



From Haul Trucks to Control Rooms: Understanding Neuro-Workload and Fatigue Burden for Safer Site Scheduling

2026 Workplace Safety North | Sudbury, ON, Canada | 04/16/2026

Emily Tetzlaff, PhD

PRESENTATION OVERVIEW

Meet Your Presenter



Dr. Emily Tetzlaff
PhD, R.Kin, MHK, BPHE, CERT-GERO

Principal Scientist, EHS
Wenco International Mining Systems Ltd.

ResearchGate Profile: [E. Tetzlaff, PhD](#)
Google Scholar Profile: [E. Tetzlaff, PhD](#)
Scopus ID: 57195543527
Web of Science ResearcherID: EDC-2209-2022
ORCID: 0000-0002-4192-474X
Citations: 466+
h-Index: 11
Publications: 40

- **The Core Problem** *Scheduling Hasn't Kept Up with Cognitive Demands*
- **Why This Matters** *Fatigue Risk Is Not Just About Hours*
- **Research Objective** *What We Set Out to Understand*
- **Methodology Overview** *How We Measured Neuro-Workload*
- **Key Metrics Defined** *What We Actually Measured*
- **Roles Analyzed** *Cross-Functional Comparison*
- **Key Findings**
 - #1 *Circadian Alignment*
 - #2 *Individual Differences*
 - #3 *Response to High-Intensity Event*
 - #4 *Day vs. Night Shift*
 - #5 *Role/Equipment Type*
- **From Insight to Action** *What This Enables*
- **Closing Message** *Rethinking Scheduling for Modern Mining*

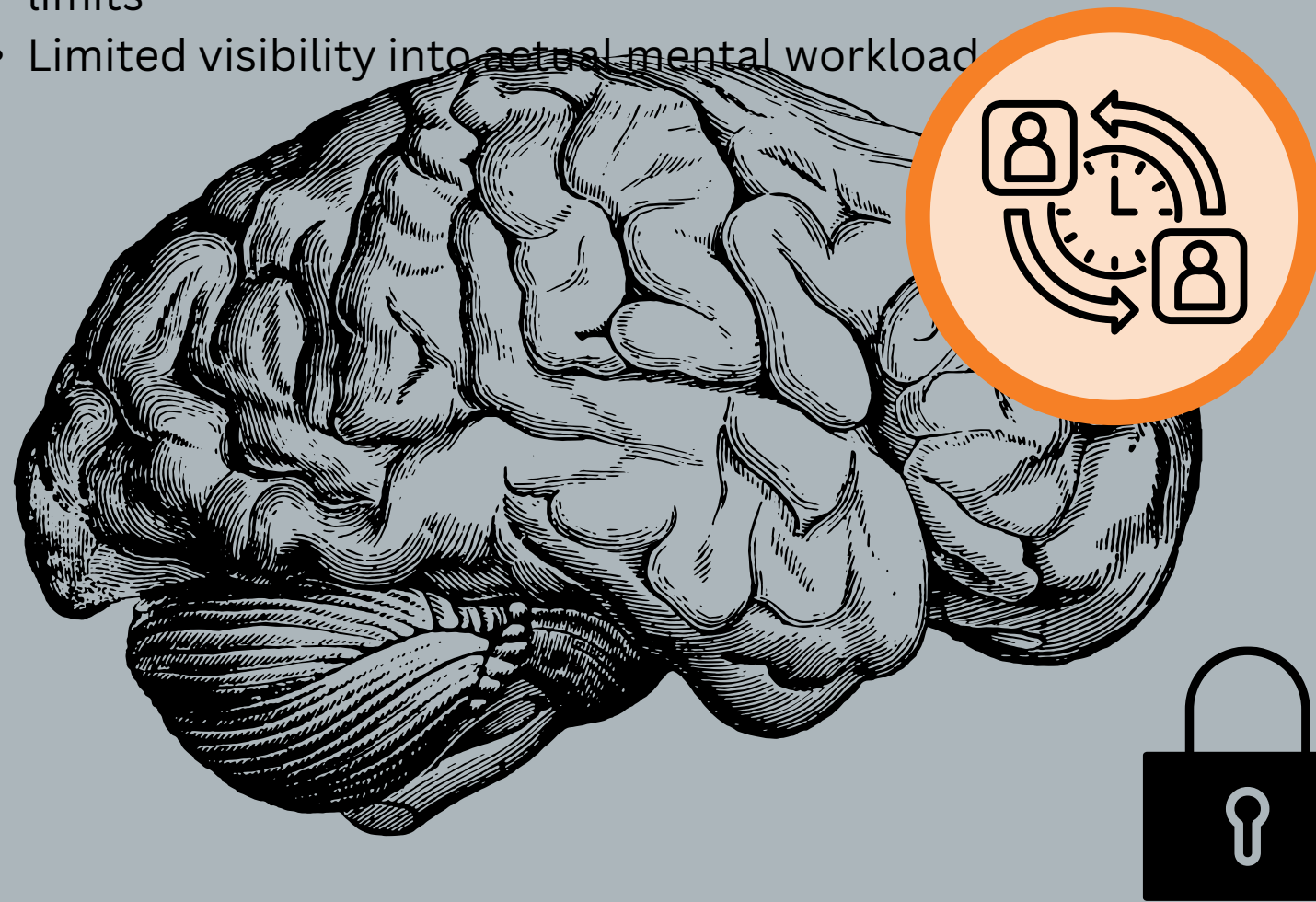
THE CORE PROBLEM

SCHEDULING HASN'T KEPT UP WITH COGNITIVE DEMANDS

Mining work has evolved, but the way we schedule it largely hasn't. This creates a growing mismatch between operational demands and fatigue risk management.

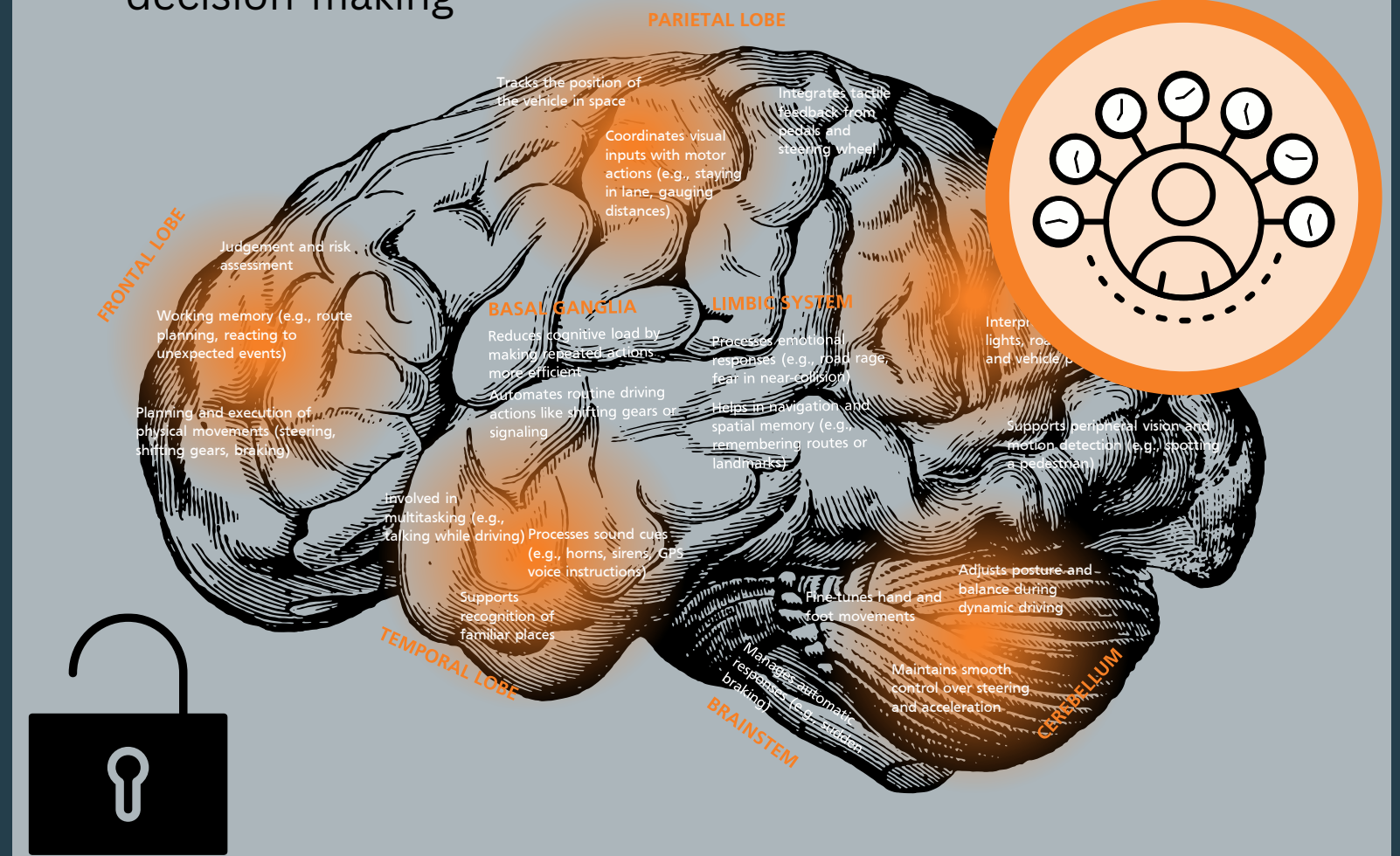
Hours-of-Service Model

- Scheduling models still anchored in hours-of-service limits
- Limited visibility into actual mental workload



Actual Work

- Operators managing complexity, variability, and real-time decision-making



BUILT ON CIRCADIAN SCIENCE

A FLAW IN THE FOUNDATION OF THE HOURS OF SERVICE MODEL

Hours-of-service regulations are grounded in our understanding of circadian rhythms and sleep need, aiming to limit fatigue by controlling work and rest periods. However, they simplify a complex biological system into time-based rules.

CIRCADIAN RHYTHM

Circadian rhythm is the body's natural 24-hour internal clock that regulates sleep, hormones, metabolism, and other physiological processes. The circadian rhythm is influenced by environmental cues, such as light, temperature, and social activity.

Circadian alignment

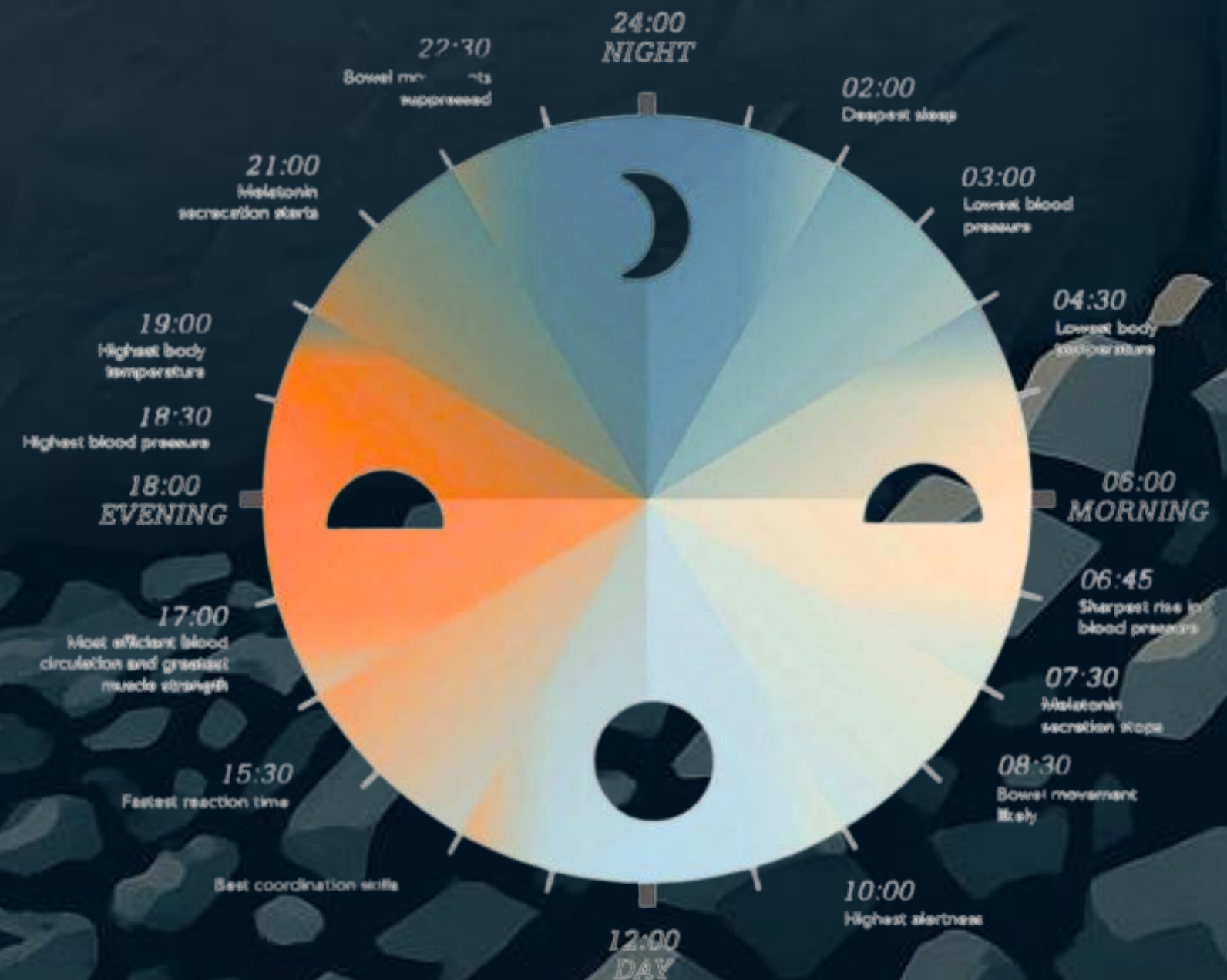
- Humans have predictable peaks and troughs in alertness
- Aims to reduce exposure during high-risk biological windows

Sleep opportunity is used as a proxy for recovery

- Mandatory rest periods are intended to allow sufficient sleep
- Assumes workers will obtain adequate, quality sleep during these windows

Fatigue risk is treated as time-dependent

- Focus on hours worked, shift length, and time since last rest
- Implies fatigue increases linearly with time-on-task



WHY THIS MATTERS

FATIGUE RISK IS NOT JUST ABOUT HOURS

Fatigue risk is no longer just about time-on-task, it's about cognitive strain and recovery capacity. Cognitive overload can occur even in shorter shifts, and underload and monotony can also degrade alertness.

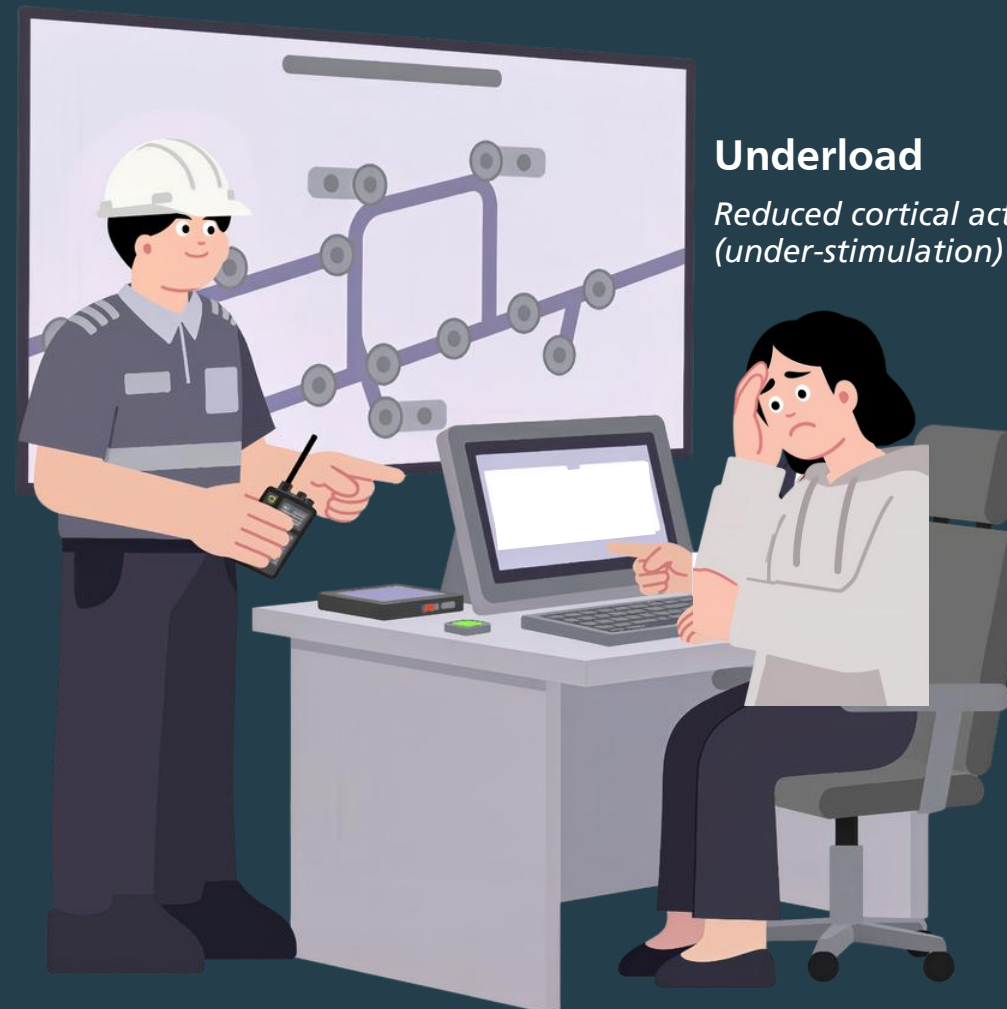


Overload

Sustained high prefrontal cortex activation

Managing a high-traffic control room during a system upset.

- Multiple alarms, radio calls, and competing screens
- Rapid prioritization and decision-making required
- Time pressure and high consequence environment



Underload

Reduced cortical activation (under-stimulation)

Monitoring a stable haul truck route with no variability.

- Autonomous or highly predictable operation
- Minimal decision-making required
- Long stretches of uneventful driving or screen watching



Optimal Load

Moderate, sustained activation

Coordinating haul cycles with moderate variability and support tools

- Steady flow of decisions, but manageable pace
- Some variability keeps engagement high
- Decision aids and systems reduce unnecessary load

RESEARCH OBJECTIVE

WHAT WE SET OUT TO UNDERSTAND

This study aimed to quantify how fatigue and cognitive demand vary across roles and over

MEASURE



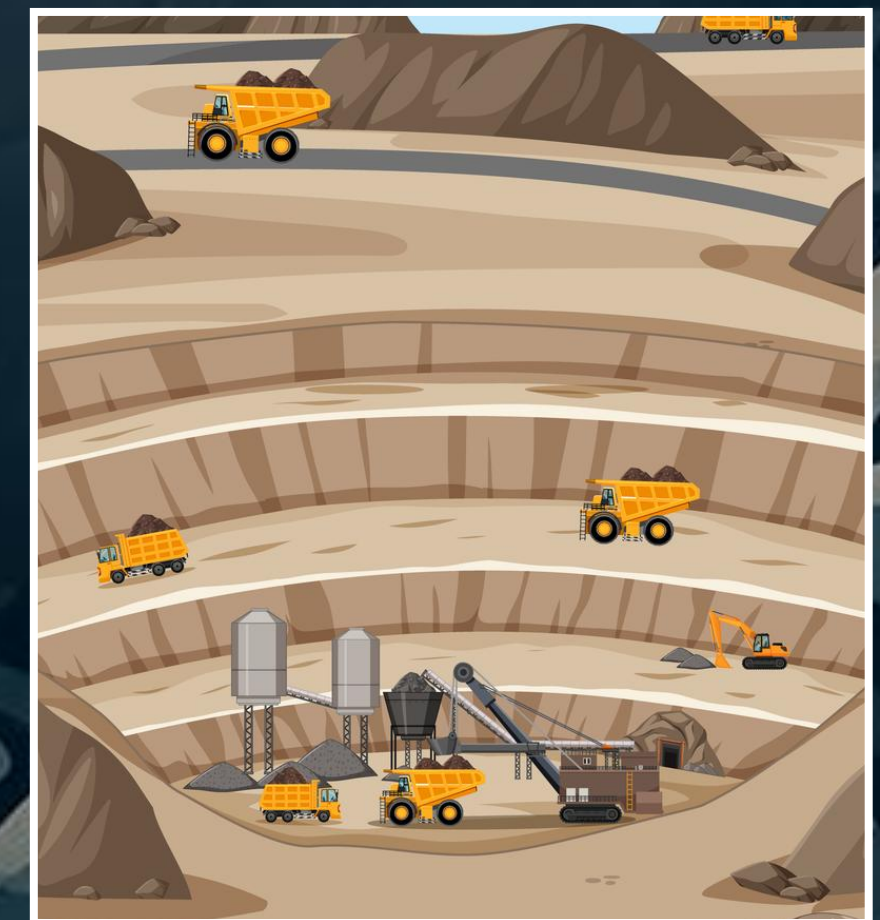
Measure neuro-workload in real operating environments

time. COMPARE



Identify when fatigue emerges within and across shifts and **compare** patterns across different job functions

APPLY



Translate findings into practical **applications** and scheduling strategies

METHODOLOGY OVERVIEW

HOW WE MEASURED NEURO-WORKLOAD

We combined physiological monitoring (**SmartCap**) with operational context to understand not just fatigue but why it occurs. Detecting cognitive fatigue can be done using electroencephalogram (EEG) traces, which involve analyzing shifts in brainwave patterns that reflect reduced mental alertness, attention, or executive function.



GAMMA

30-100 Hz
Higher cognitive functions

BETA

13-30 Hz
Alert, active thinking

ALPHA

8-13 Hz
Relaxed wakefulness

THETA

4-8 Hz
Drowsiness, early sleep

DELTA

0.5-4 Hz
Sleep

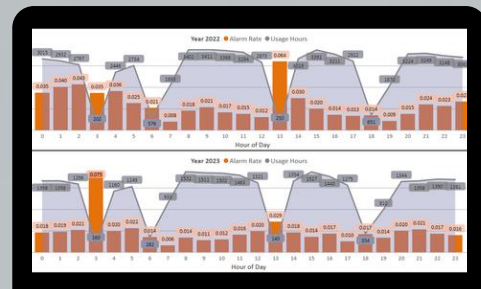
Waveforms: Fast and Peaking
Frequency: Higher
Amplitude: Lower

Waveforms: Slowing and Flattening
Frequency: Lower
Amplitude: Higher

KEY METRICS DEFINED

WHAT WE ACTUALLY MEASURED

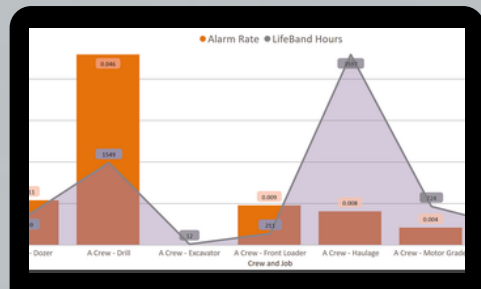
A number of core indicators were used to quantify fatigue risk and cognitive demand.



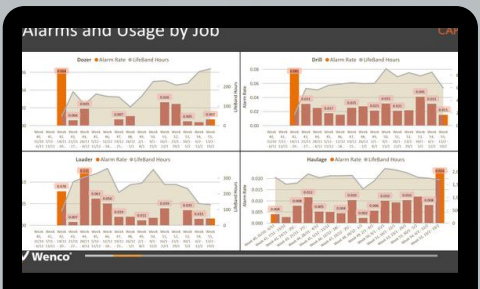
Alarm Rate and Usage Hours by Hour of Day



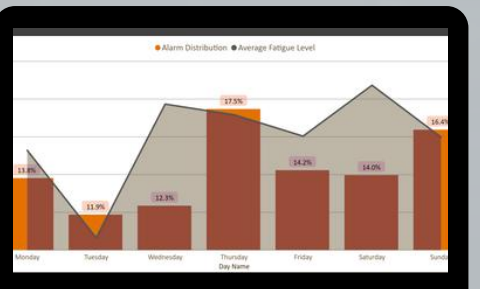
Alarm Rate and Usage by Day of Week



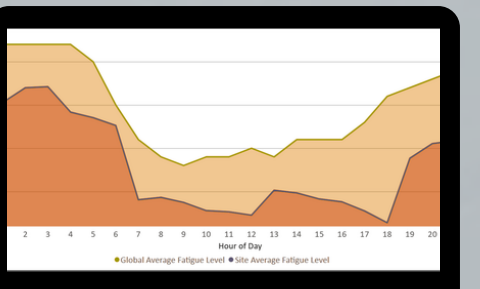
Fatigue Risk by Crew and Job



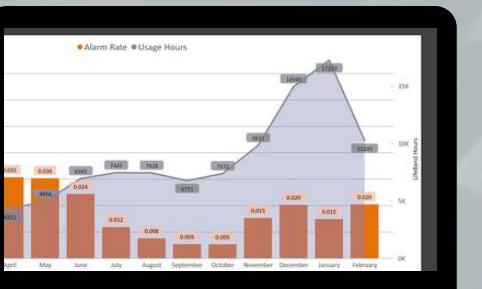
Alarms and Usage by Job



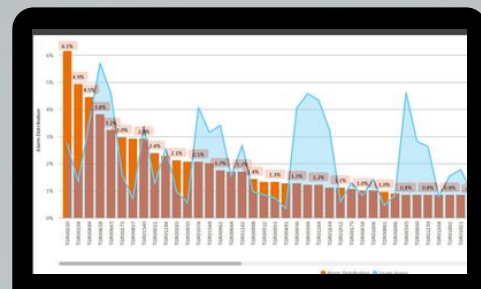
Average Fatigue Level and Alarm Distribution



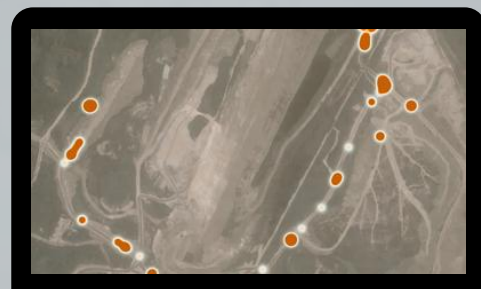
Site Fatigue v. Global Fatigue



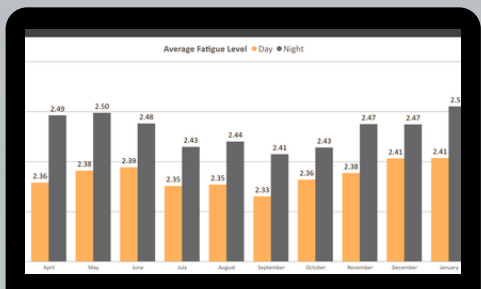
Alarm Rate and Usage by Month



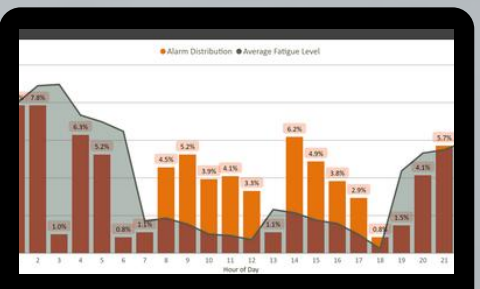
Alarm Distribution and Usage by Operator



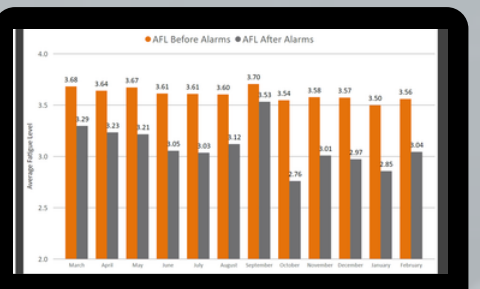
Fatigue Map



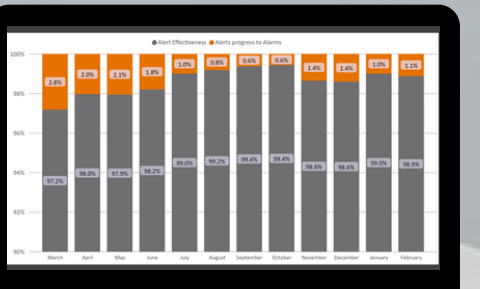
Average Fatigue Level: Day Shift v. Night Shift



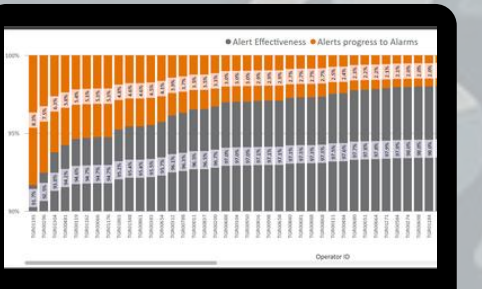
Average Fatigue Level and Alarm Distribution



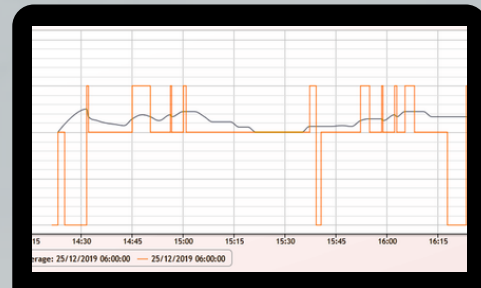
Post Alarm Fatigue Improvement



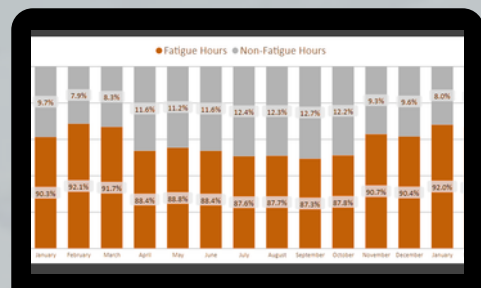
Self-Management Effectiveness



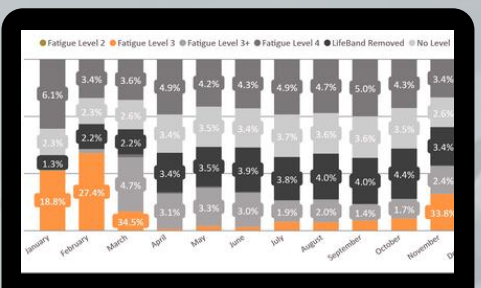
Self-Management Effectiveness by Operator



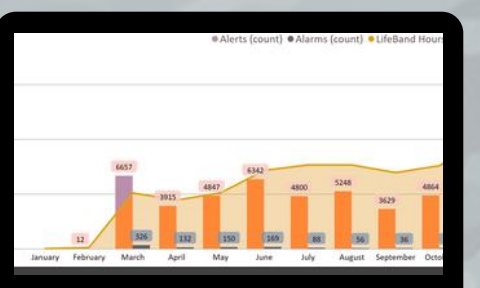
Fatigue Trace



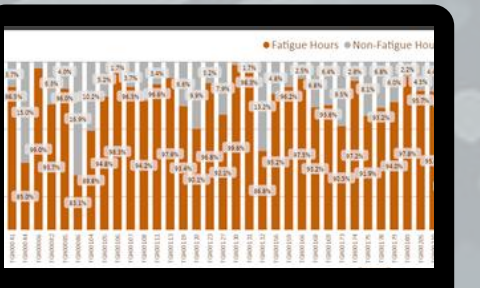
Operator Effectiveness at Managing Fatigue



Fatigue Level Distribution



Early Warning Alerts and Fatigue Alarms



Fatigue Hours v. Non-Fatigued Hours

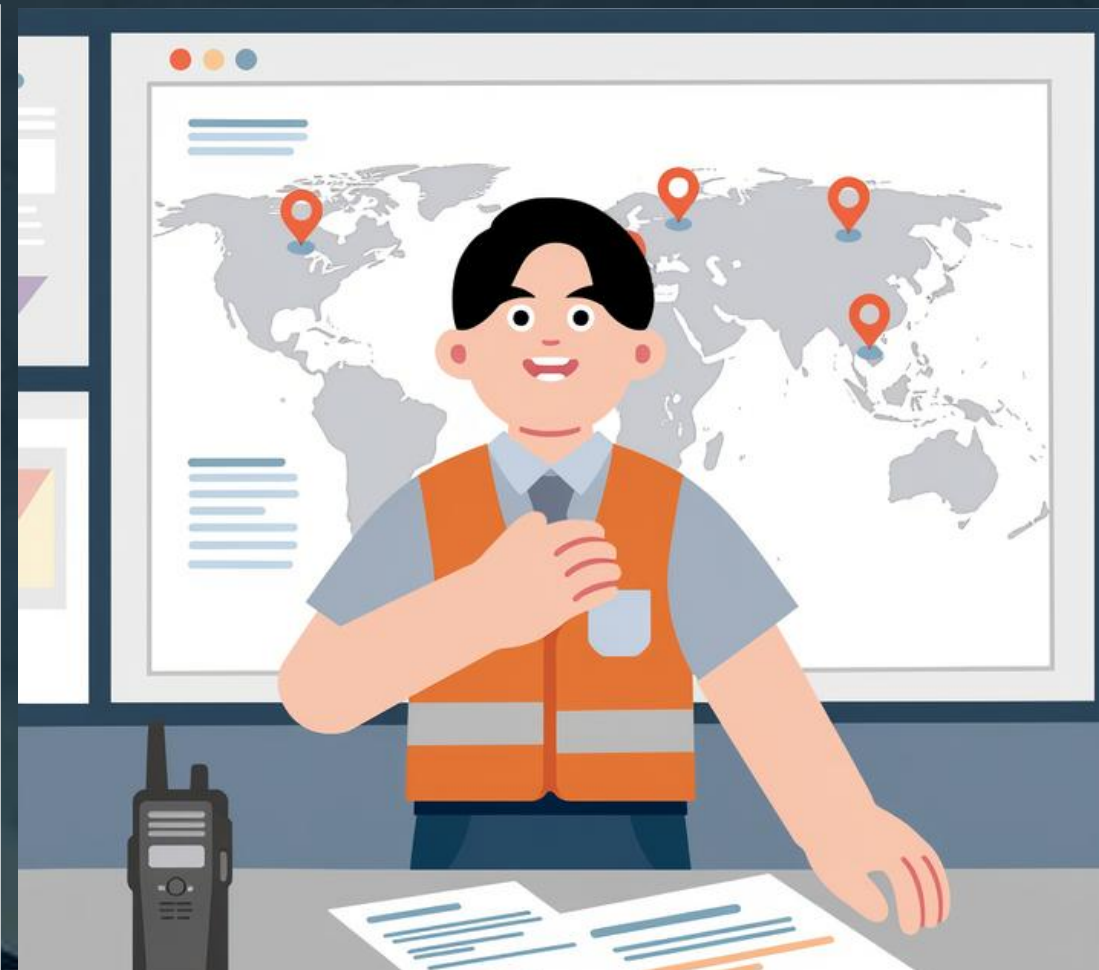
ROLES ANALYZED

CROSS-FUNCTIONAL COMPARISON

We examined fatigue patterns across key operational roles with distinct task demands. This is key because treating all roles the same masks critical differences in fatigue exposure and risk. Different task structures drive different cognitive demands and therefore need different fatigue management approaches.



Haul Truck Operators



Control Room Employees



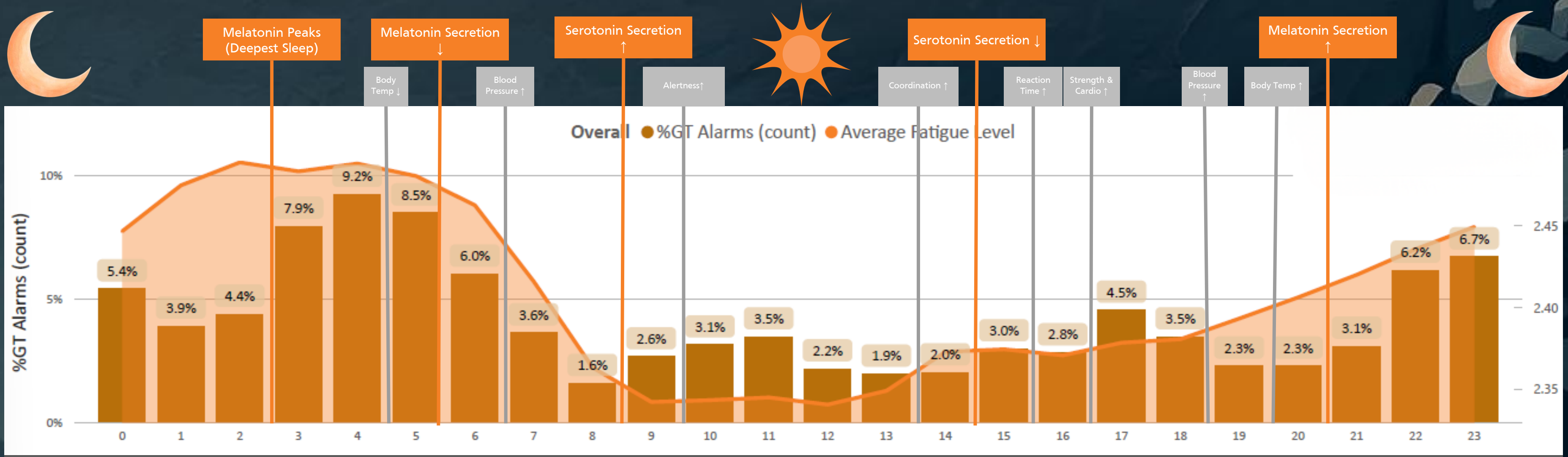
Transport Vehicle Drivers



KEY FINDING #1

CIRCADIAN RHYTHM: THE BASELINE, NOT THE WHOLE STORY

Predictable peaks (daytime) and troughs (early morning, mid-afternoon) are evident in the data, which align with the circadian rhythm. Although this provides a predictable baseline for alertness, it assumes a relatively uniform fatigue response across workers and **does not account for task demand, environment, or individual variability.**





KEY FINDING #2

INDIVIDUAL DIFFERENCES

Even under identical conditions, fatigue responses vary significantly between individuals. Standardized schedules assume uniform capacity but the data shows uneven vulnerability. Some operators enter high-risk states earlier, whereas others maintain stable performance longer.

Wenco From One-Size-Fits-All to Real-Time, Personalized Protection
A Case from a Wenco Work Trip

When the Scientist Becomes the Subject: A Real-World Look at Jet Lag Fatigue

BACKGROUND
Even experts aren't immune to fatigue. Long-distance travel across multiple time zones is a well-known contributor to fatigue. Rapid shifts in sleep-wake cycles, irregular rest opportunities, and demanding schedules can all impair alertness. For safety-critical industries, this isn't just a personal inconvenience, it's a real operational risk.

THE INCIDENT
A live demonstration turns into a real-time fatigue event:
While traveling from Toronto → Vancouver → Brisbane → Perth → a remote mine site, the Principal Specialist for SmartCap experienced significant jet lag. During a product demonstration at site, the SmartCap wearable repeatedly issued fatigue alerts and warnings on the scientist herself!

FATIGUE RISK MANAGEMENT
Data doesn't lie. EEG traces collected throughout the trip showed a clear decline in alertness, with elevated fatigue scores coinciding with local night-time hours at the traveler's origin. The real-time alerts acted exactly as they would for an operator, validating the system's sensitivity to physiological changes during circadian disruption.

FUTURE-PROOF FATIGUE MANAGEMENT
Fatigue is universal. Data makes it visible. Jet lag can affect anyone, anywhere, and without objective tools, its effects often go unnoticed until performance drops. As this example illustrates, fatigue can impact anyone, including experts, and highlights the need for objective, continuous monitoring rather than relying on self-assessment alone.

Wenco Unintended Health & Wellness Insights Enabled by SmartCap
A Case from a Long Time SmartCap User

Fatigue as a Window into Worker Wellbeing: A Nutrition-Related SmartCap Case Study

BACKGROUND
Fatigue risk management programs are typically implemented to reduce safety incidents and protect operational performance. However, when fatigue is measured directly through brain activity, the data can reveal broader patterns related to health, wellbeing, and recovery. Recently, an operator at an open-pit gold operation in South America demonstrated this value.

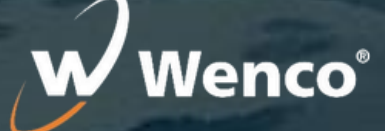
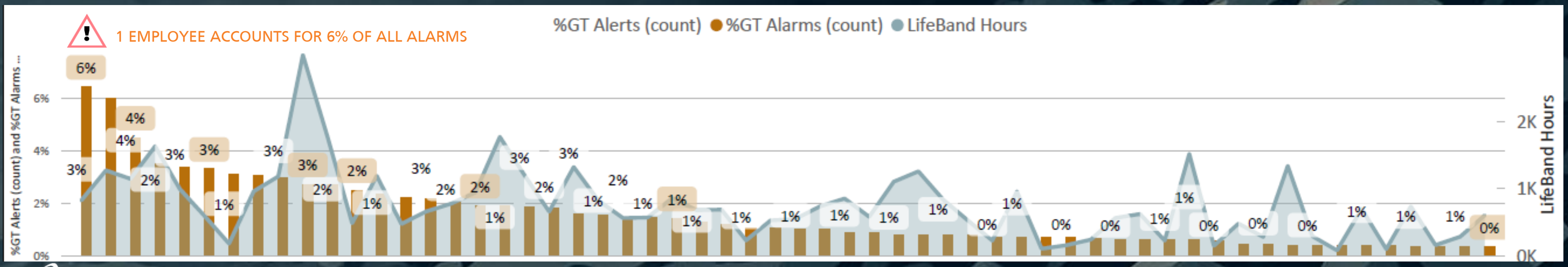
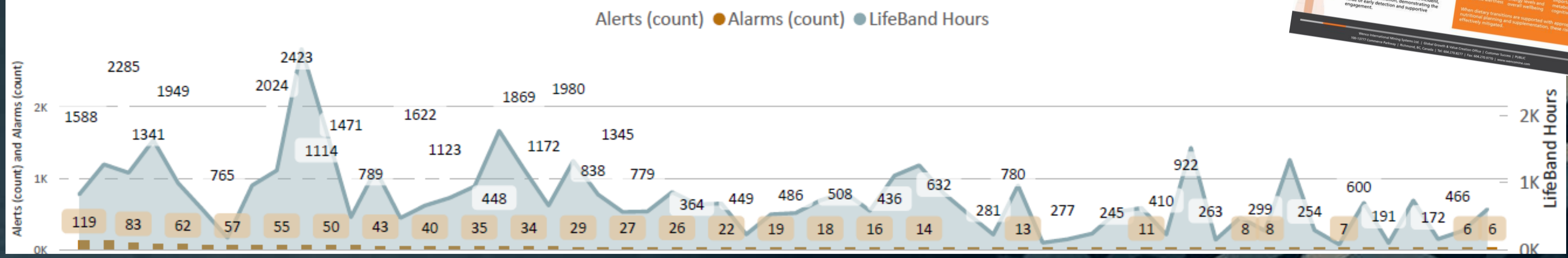
NORMAL FATIGUE PROFILE
Since the implementation of the SmartCap program, the operator had a well-established fatigue baseline:
• Consistently low fatigue alerts over time
• Effective self-management using SmartCap warnings
• No recurring trends flagged in daily or shift reports
This pattern had been stable for months and aligned with the operator's performance and wellbeing at work.

CHANGE DETECTED WITH SMARTCAP
But, dispatchers and supervisors began to notice a change. The operator's name was appearing more frequently in the live dashboard and daily fatigue reports, despite no changes to the shift schedule or role. Importantly, these changes were identified through trend monitoring across multiple shifts, not a single event.

ROOT CAUSE
Rather than treating the data as a disciplinary issue, the OHS team probed, confidential conversation focused on understanding potential contributing factors. During the conversation, the employee shared that they had recently transitioned to a vegan diet.

SUPPORTIVE INTERVENTION
With guidance, the employee adjusted their diet to better support energy, recovery, and sustained alertness. Following these adjustments, the employee's fatigue alerts effectiveness improved and the employee reported improved energy and wellbeing. The situation was resolved without incident, value of early detection and supportive engagement.

NUTRITION & FATIGUE SIGNALS
When not carefully managed, dietary changes can influence energy levels, recovery, and sustained alertness. In plant-associated work, heightened fatigue has been associated with insufficient intake or absorption of key nutrients, including:
• **B12**: Essential for neurological function and energy metabolism
• **Iron**: Critical for oxygen transport; low levels can increase perceived fatigue
• **Omega-3**: Fatty acids linked to cognitive function and mental endurance
• **Vitamin D**: Associated with energy levels and overall wellbeing
• **Zinc** and **Iodine**: Important for metabolic and cognitive processes
When dietary transitions are supported with appropriate nutritional planning and supplementation, these risks can be effectively mitigated.





KEY FINDING #2

INDIVIDUAL DIFFERENCES

Mental Health
Medications
Commuting Time
Caregiving Duties



Time-on-Task
Monotonous Work
High Mental Demand
High Physical Workload



Shift schedule
Shift length
Break frequency/timing
Cumulative hours



Environmental Conditions
Workplace Culture
Reporting Policies
Overtime incentives



Nutrition/hydration
Caffeine/stimulant use
Alcohol and drug use
Physical fitness



Sleep quantity
Sleep quality
Sleep disorders
Circadian rhythm
Chronotype





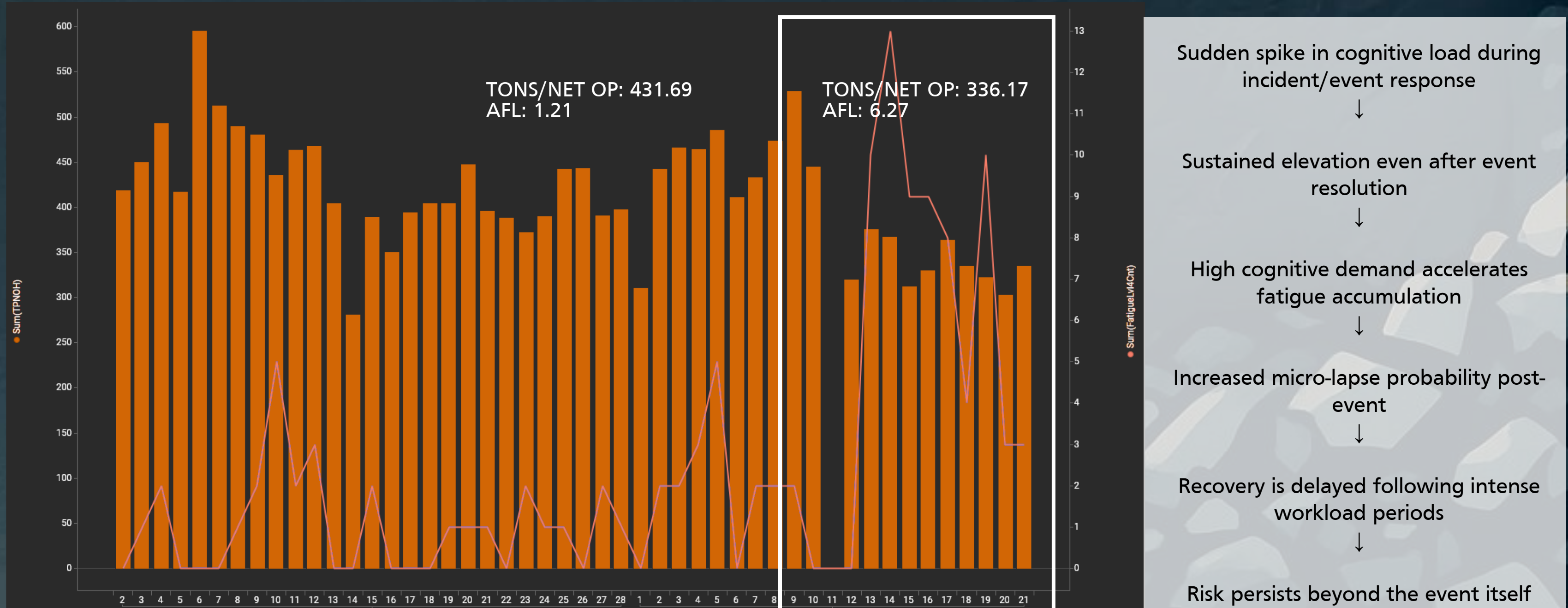
KEY FINDING #3

RESPONSE TO A HIGH-INTENSITY EVENT



NEARLY 100 TONS DIFFERENCE AND 5X INCREASE IN FATIGUE LEVEL

Acute operational events can override circadian patterns and rapidly elevate fatigue risk.



Note: Tons/Net Op Hour represents how many tons they mined in a net operating hour (85% of actual hour) with strip ratio & grade





KEY FINDING #4

DAY VS NIGHT SHIFT

Night shift data shows expected baseline fatigue elevation; however, circadian rhythm explains part of the difference between day and night shifts. Day shift may still experience fatigue spikes during high-demand windows

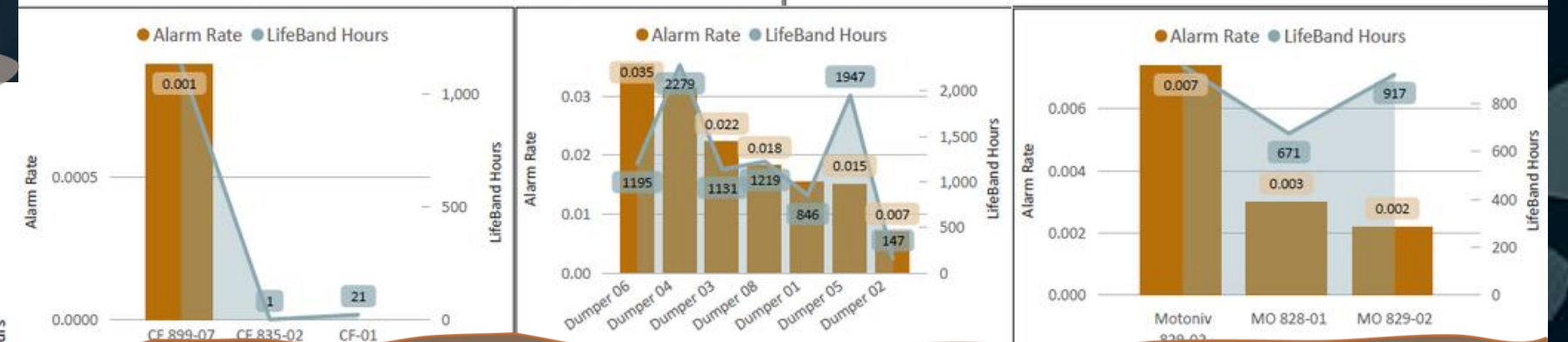
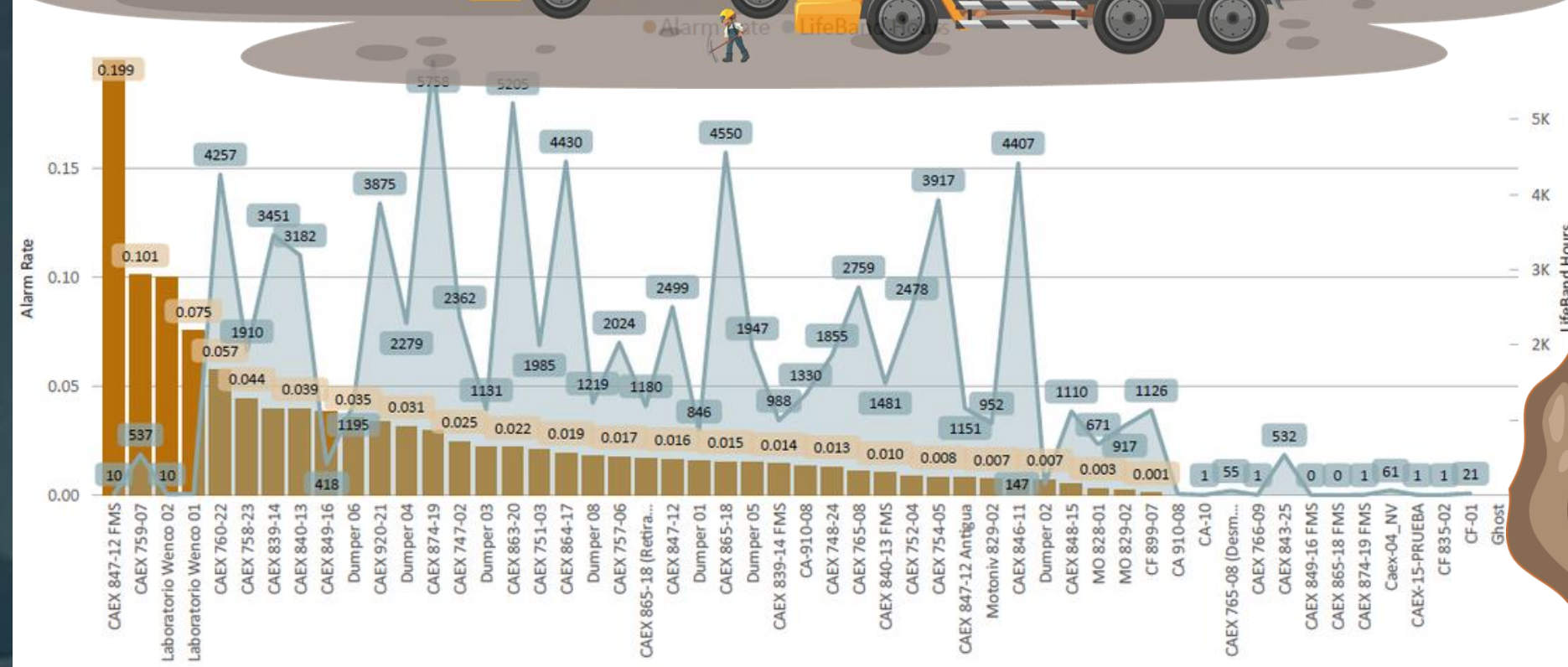




KEY FINDING #5

ROLE / EQUIPMENT TYPE

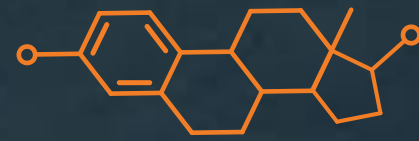
Different equipment and roles create fundamentally different cognitive demand profiles. For example, haul trucks often have early-shift cognitive spikes, control rooms have sustained, high-density workload, and transport personnel have prolonged monotony and extended exposures.



THE PHYSIOLOGY OF FATIGUE

A MEASURABLE NEUROPHYSIOLOGICAL RESPONSE TO SUSTAINED COGNITIVE DEMAND

As mental effort increases, the brain undergoes metabolic, chemical, and functional changes that directly impact performance.



Energy Depletion

Intense mental activity increases glucose utilization in the brain

Neurotransmitters such as **dopamine** are **consumed** during sustained effort

Reduced availability weakens signalling efficiency

Most impacted region: prefrontal cortex

Neurochemical Fatigue

Prolonged cognitive effort leads to the **accumulation** of **adenosine**

Adenosine inhibits neural activity and promotes sleep pressure

Results in:

- Slower reaction times
- Reduced vigilance
- Mental "fog"

Network Disruption

Sustained load **disrupts communication** between key brain networks:

- Task-positive (focus, execution)
- Default mode (rest, mind-wandering)

Leads to:

- Decreased working memory
- Reduced attentional control
- Increased variability in performance

Neuroinflammatory Response

High cognitive strain can trigger low-level **neuroinflammation**

Associated with reduced motivation and cognitive efficiency

Amplifies fatigue effects over time

Protective Down-Regulation

The brain actively regulates effort to prevent overload
Shifts from:

Goal-directed behavior → **reward-seeking or disengagement**

Manifested as:

- Loss of focus
- Increased errors
- Desire to stop or switch tasks

FROM INSIGHT TO ACTION

WHAT THIS ENABLES

These findings enable a shift from reactive to proactive fatigue management. Neuro-workload insights can be directly translated into actionable scheduling improvements to improve safety and performance.

Practical Applications: Neuro-Responsive Scheduling Strategies

- Optimize break timing around cognitive peaks
- Redistribute high-load tasks across teams
- Adjust shift design based on role-specific demand
- Incorporate circadian-informed scheduling principles
- Identify high-risk windows with precision
- Align work with cognitive readiness
- Move from compliance-based to risk-based scheduling
- Enable data-informed operational decisions



Wenco Getting More Out of Your Mine | From One-Size-Fits-All to Real-Time, Personalized Protection
A Case from a Precious Metal Open-Pit Mine in North America 01/2026

Fatigue Breaks: Are We Effectively Managing Risk?

THE TIME SPENT
How much time is being spent to standard fatigue breaks?
The data shows that over **206 hours/month** is spent on prescriptive fatigue breaks (not inclusive of meal or restroom breaks) across the fleet - that represents **19% of all delay/standby time** (non-productive time). This places fatigue breaks as the second leading cause of 'time loss' for the site.

FATIGUE RISK MANAGEMENT
Prescriptive vs. Performance-Based
There are two primary approaches to fatigue risk management:

Prescriptive-Based	Performance-Based
Fixed breaks (e.g., every 2 hours)	Breaks triggered by real-time fatigue measures
One-size-fits-all policy	Tailored to individual operator needs
Disrupts production fleet-wide	Dispatch guided to select optimal timing
Regulatory compliance-focused	Risk-reduction and efficiency combined

The best approach combines both - it complies with regulatory requirements for break duration, while prioritizing performance as the driving factor.

SmartCap enables compliance and optimization.

WHAT COULD BE GAINED?
Imagine a smarter approach.

- Reduce unnecessary downtime.
- Enable targeted interventions only when fatigue risk is real.
- Keep equipment rolling when operators are alert.
- Standard operating procedures that simplifies fatigue break scheduling, improving safety and reducing impact on production.

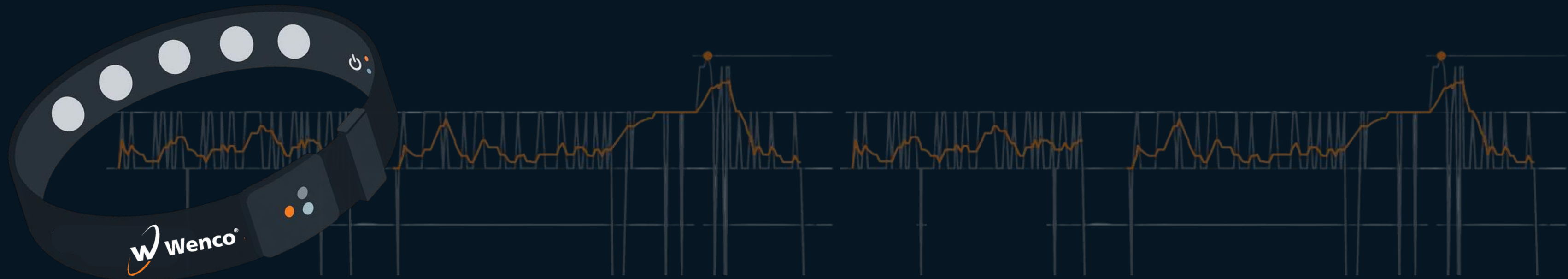
Operator breaks account for 4% of utilization annually.
It is important to note that this value doesn't represent or account for *actual fatigue* - it assumes that everyone needs the same break, at the same time. This represents a prescriptive approach to fatigue management.

NEXT STEPS
Let's move from blanket rules to data-driven decisions.
With SmartCap, you can protect your people, maintain compliance and improve production efficiency. Reach out to Wenco's Customer Success Team to find out more about optimizing your fatigue risk management approach.

CLOSING MESSAGE

RETHINKING SCHEDULING FOR MODERN MINING

To improve safety outcomes, scheduling must evolve to reflect how work is actually experienced. If fatigue risk is dynamic, our approach to managing it must be as well.



1

Move beyond hours-of-service models to risk-based models

2

Design schedules around cognitive demand by integrating biological and operational data

3

Recognize variability across roles, workload, time and recovery needs

4

Build adaptive, data-driven fatigue management systems

QUESTIONS

CONTACT INFORMATION

Dr. Emily Tetzlaff, PhD, R.Kin, MHK, BPHE, CERT-GERO



www.linkedin.com/in/emilytetzlaff



613-813-7483



etetzlaff@wencomine.com



<https://www.wencomine.com/>



100-13777 Commerce Parkway, Richmond, BC, Canada, V6V 2X3