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

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

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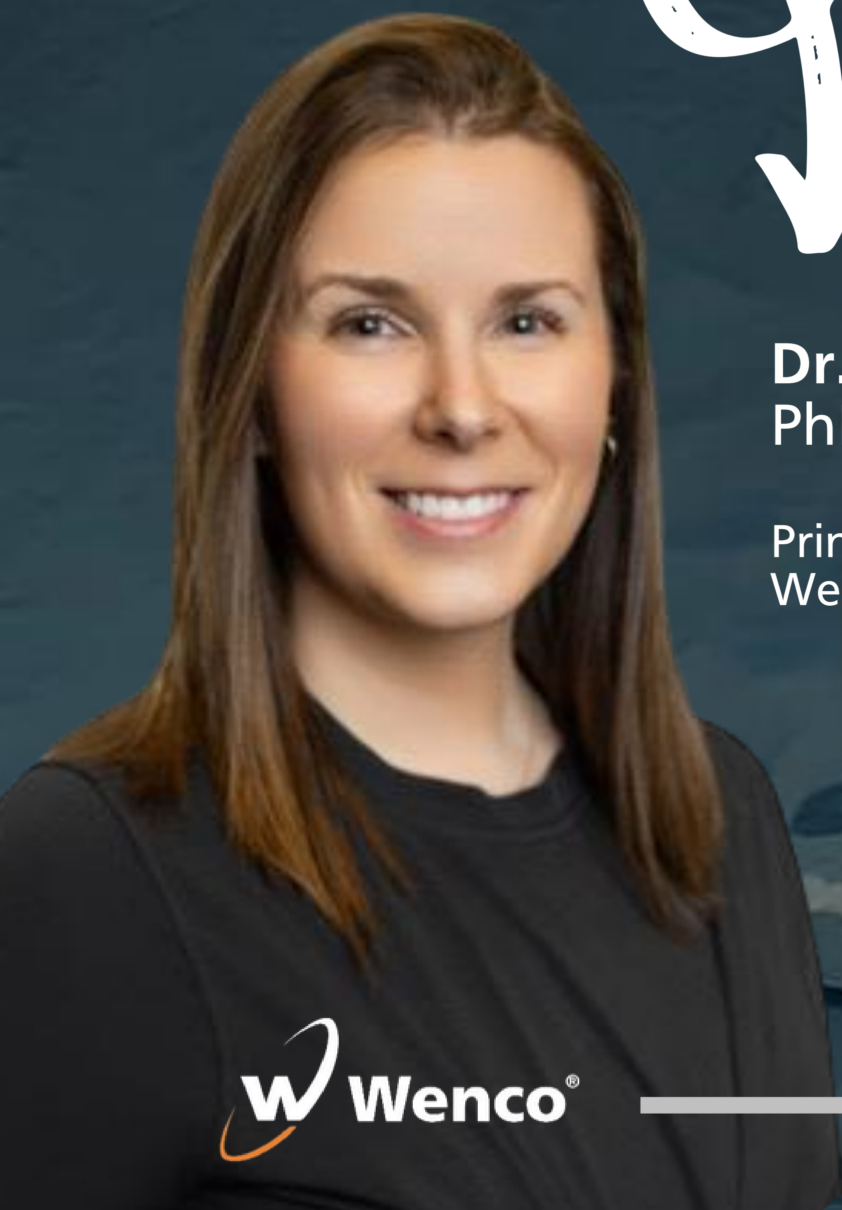
PRESENTATION OVERVIEW

Meet Your Presenter



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Citations: 466+
h-Index: 11
Publications: 40

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- **Why This Matters** *Fatigue Risk Is Not Just About Hours*
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THE CORE PROBLEM

SCHEDULING HASN'T KEPT UP WITH COGNITIVE DEMANDS

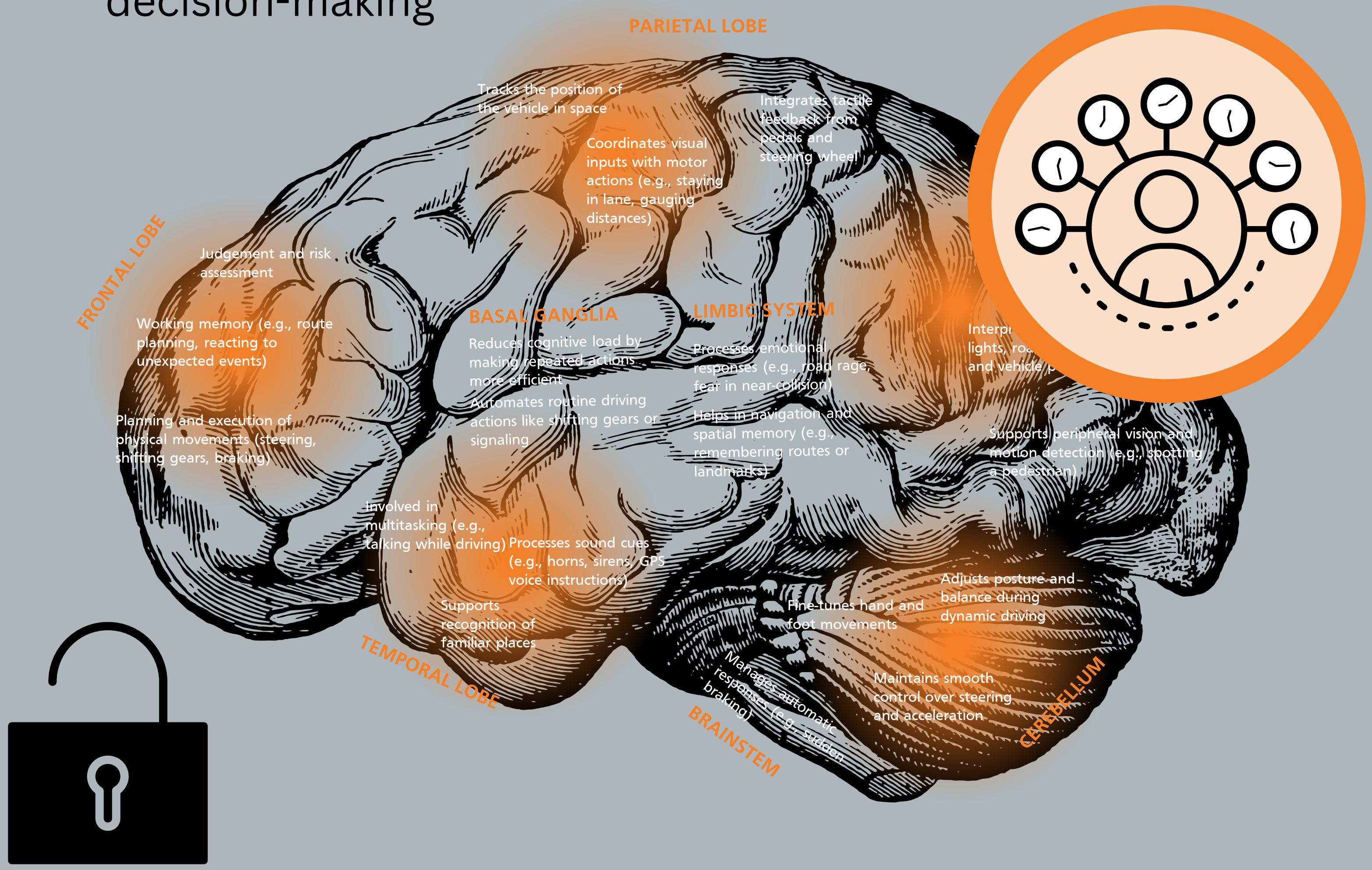
Mining work has evolved, but the way we schedule it largely hasn't. This creates a growing mismatch between operational demands and fatigue risk management.

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



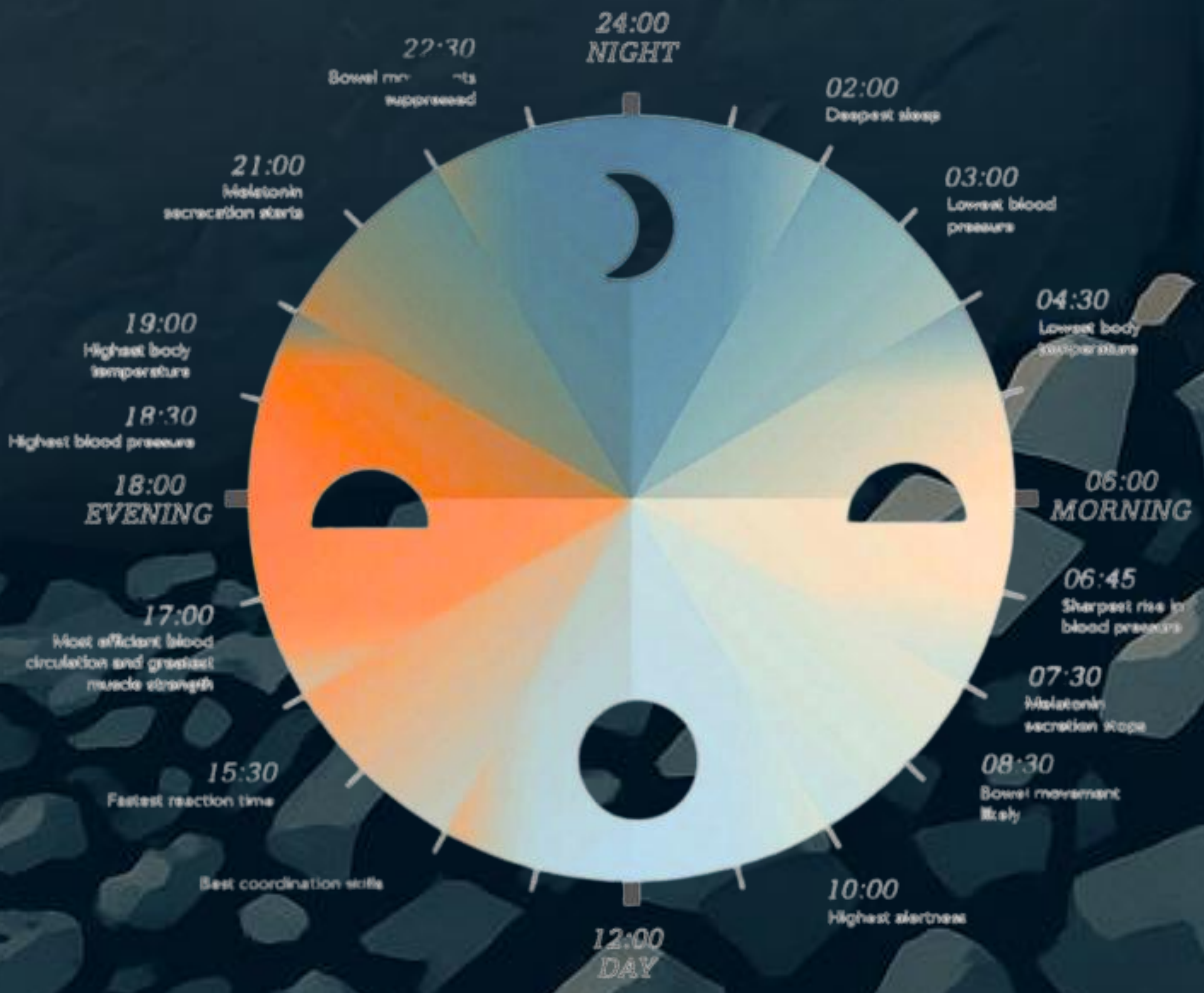
BUILT ON CIRCADIAN SCIENCE

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

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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 time.

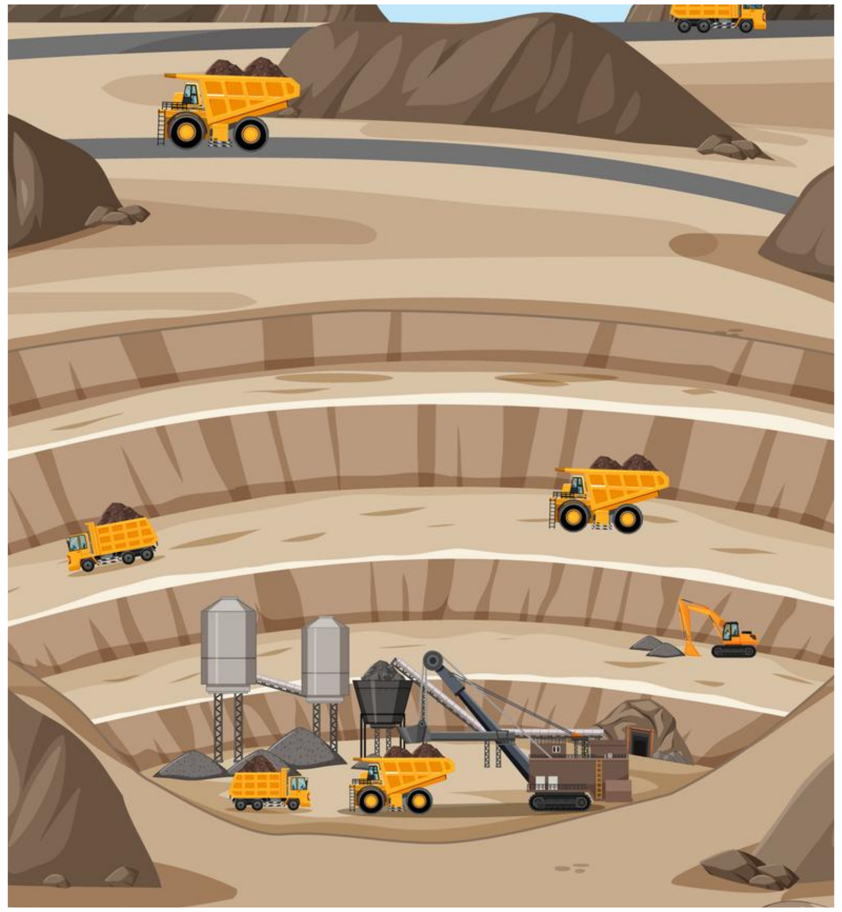
MEASURE

Measure neuro-workload in real operating environments

COMPARE

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

APPLY

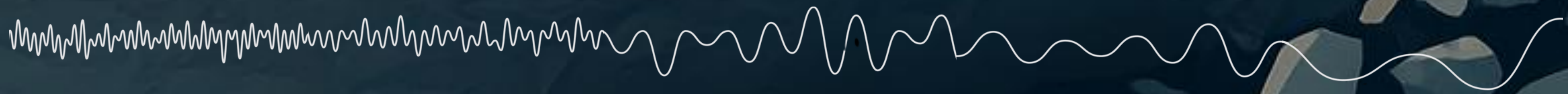


Translate findings into practical **applications** and scheduling strategies

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

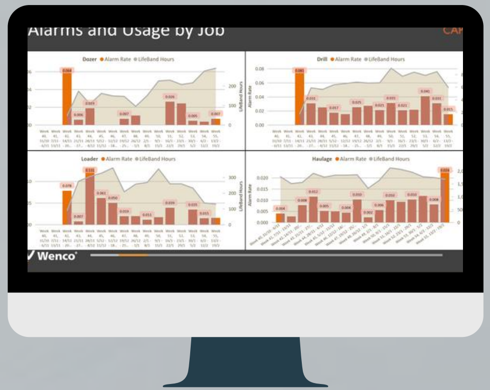
WHAT WE ACTUALLY MEASURED

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



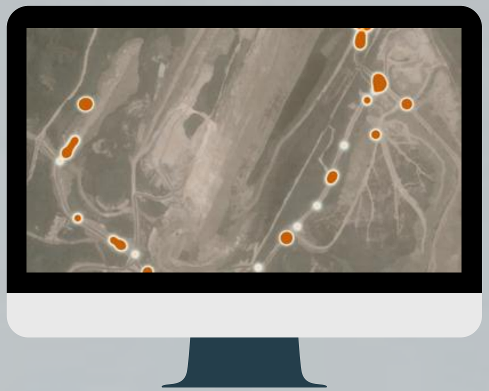
Alarms and Usage by Job

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

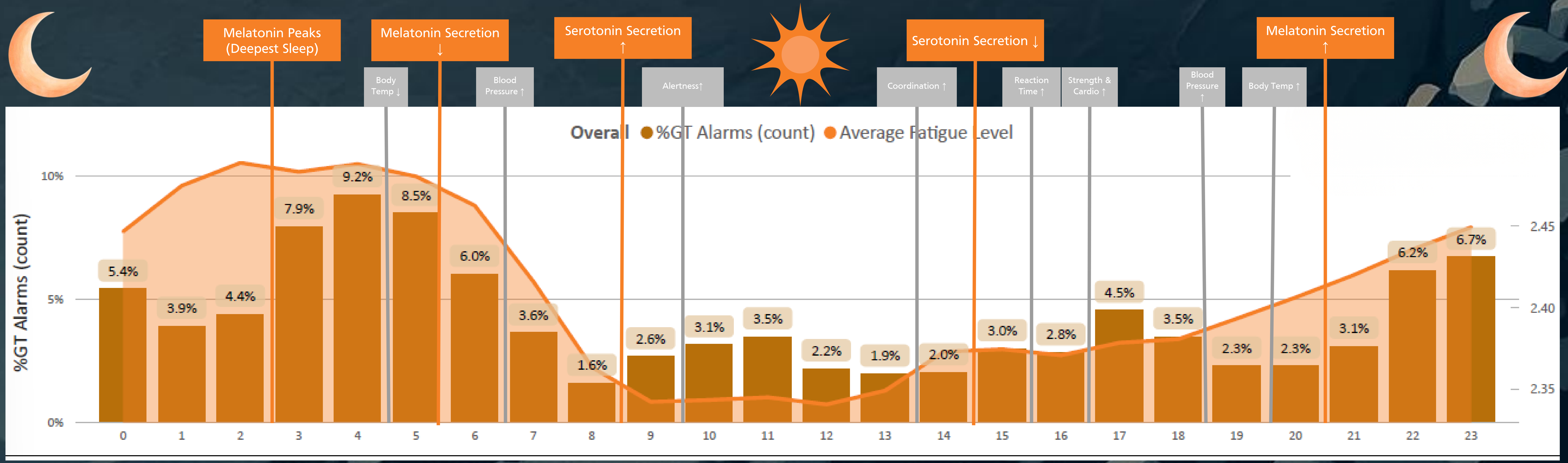
Control Room Employees

Transport Vehicle Drivers

KEY FINDING #1

CIRCADIAN RHYTHM: THE BASELINE, NOT THE WHOLE STORY

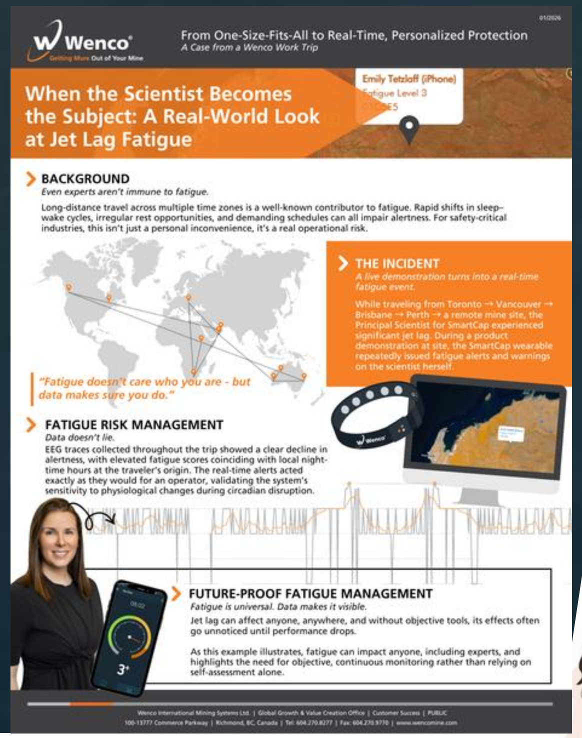
Predictable peaks (daytime) and troughs (early morning, mid-afternoon) are evident in the data, which align with the circadian rhythm. Although this provides a predictable baseline for alertness, it assumes a relatively uniform fatigue response across workers and **does not account for task demand, environment,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

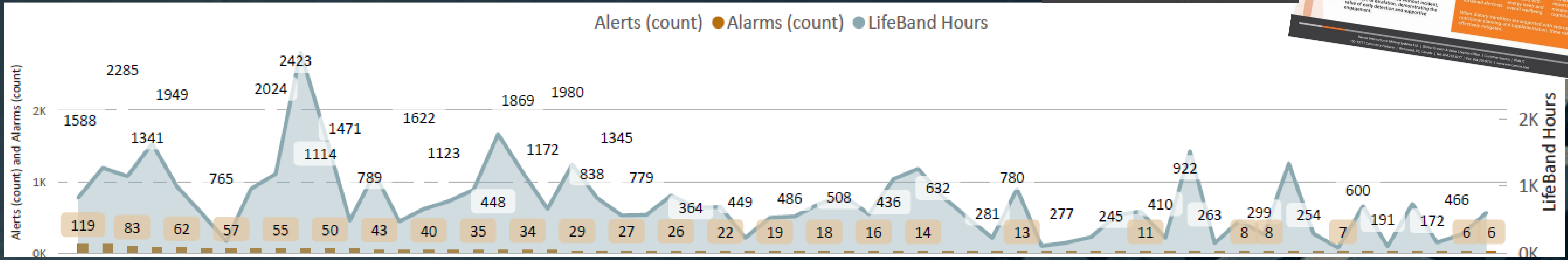


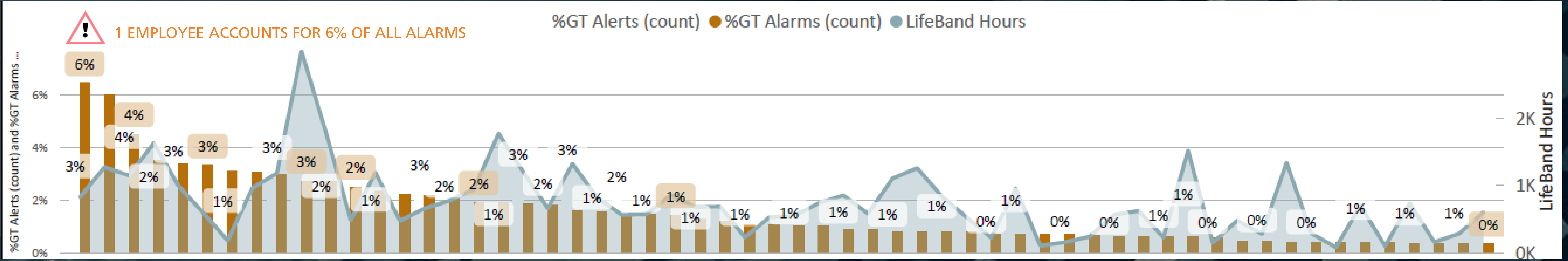
KEY FINDING #2

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.







KEY FINDING #2

INDIVIDUAL DIFFERENCES

Mental Health
Medications
Commuting Time
Caregiving Duties

Shift schedule
Shift length
Break frequency/timing
Cumulative hours

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

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

Environmental Conditions
Workplace Culture
Reporting Policies
Overtime incentives

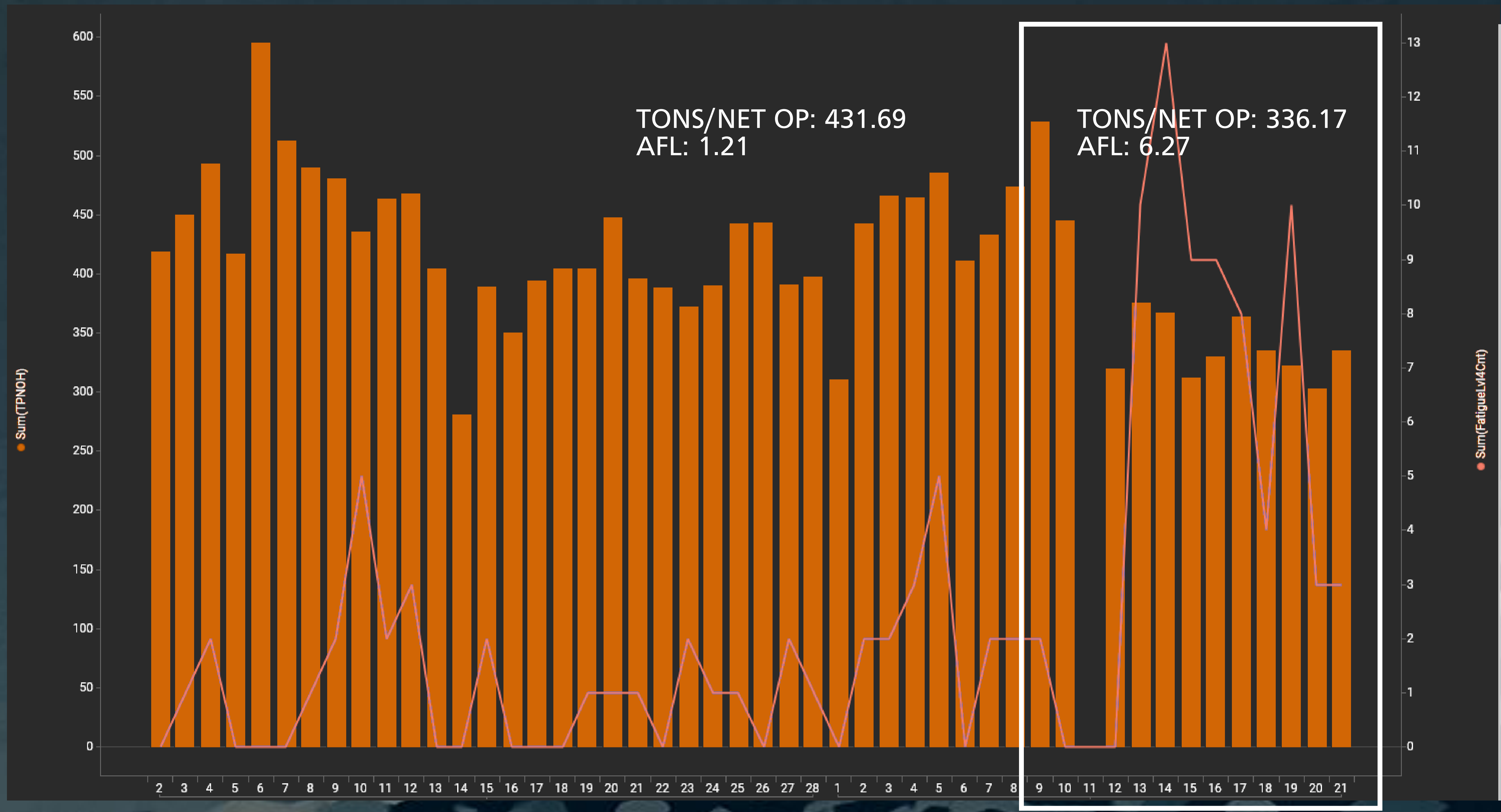
Sleep quantity
Sleep quality
Sleep disorders
Circadian rhythm
Chronotype

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.



Sudden spike in cognitive load during incident/event response

↓

Sustained elevation even after event resolution

↓

High cognitive demand accelerates fatigue accumulation

↓

Increased micro-lapse probability post-event

↓

Recovery is delayed following intense workload periods

↓

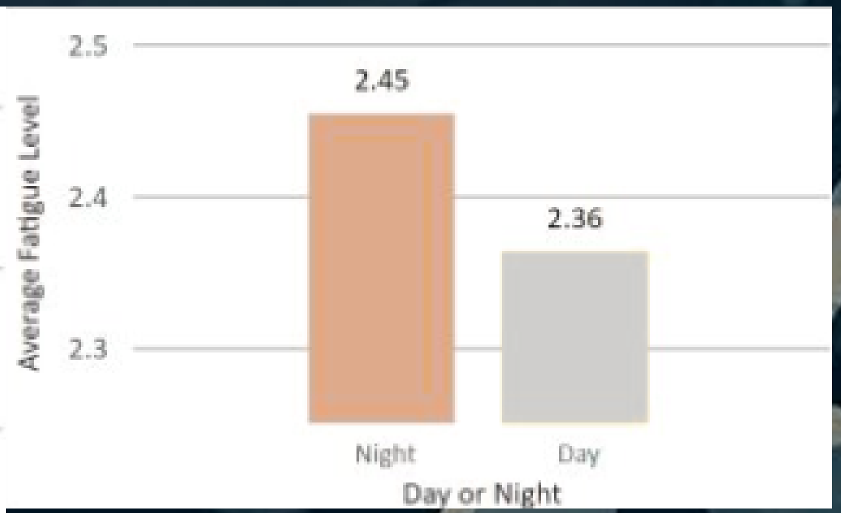
Risk persists beyond the event itself

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

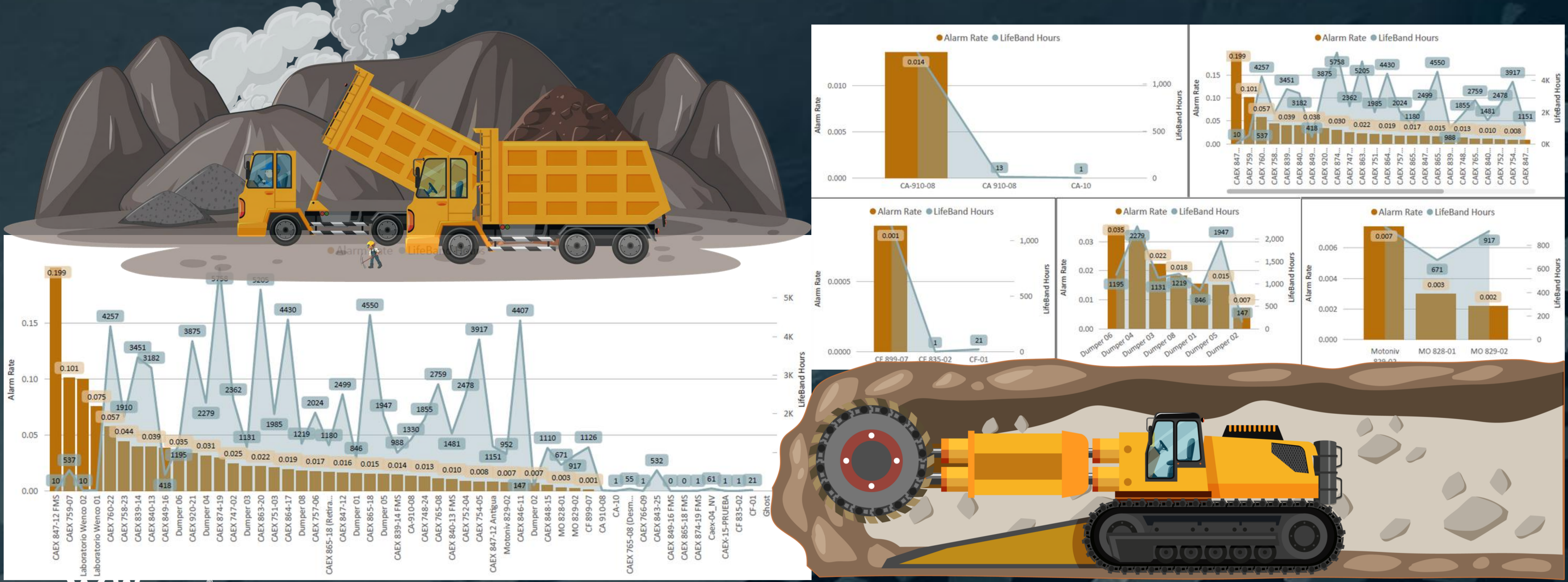
Night shift data shows expected baseline fatigue elevation; however, circadian rhythm explains part of the difference between day and night shifts. Day shift may still experience fatigue spikes during high-demand windows



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

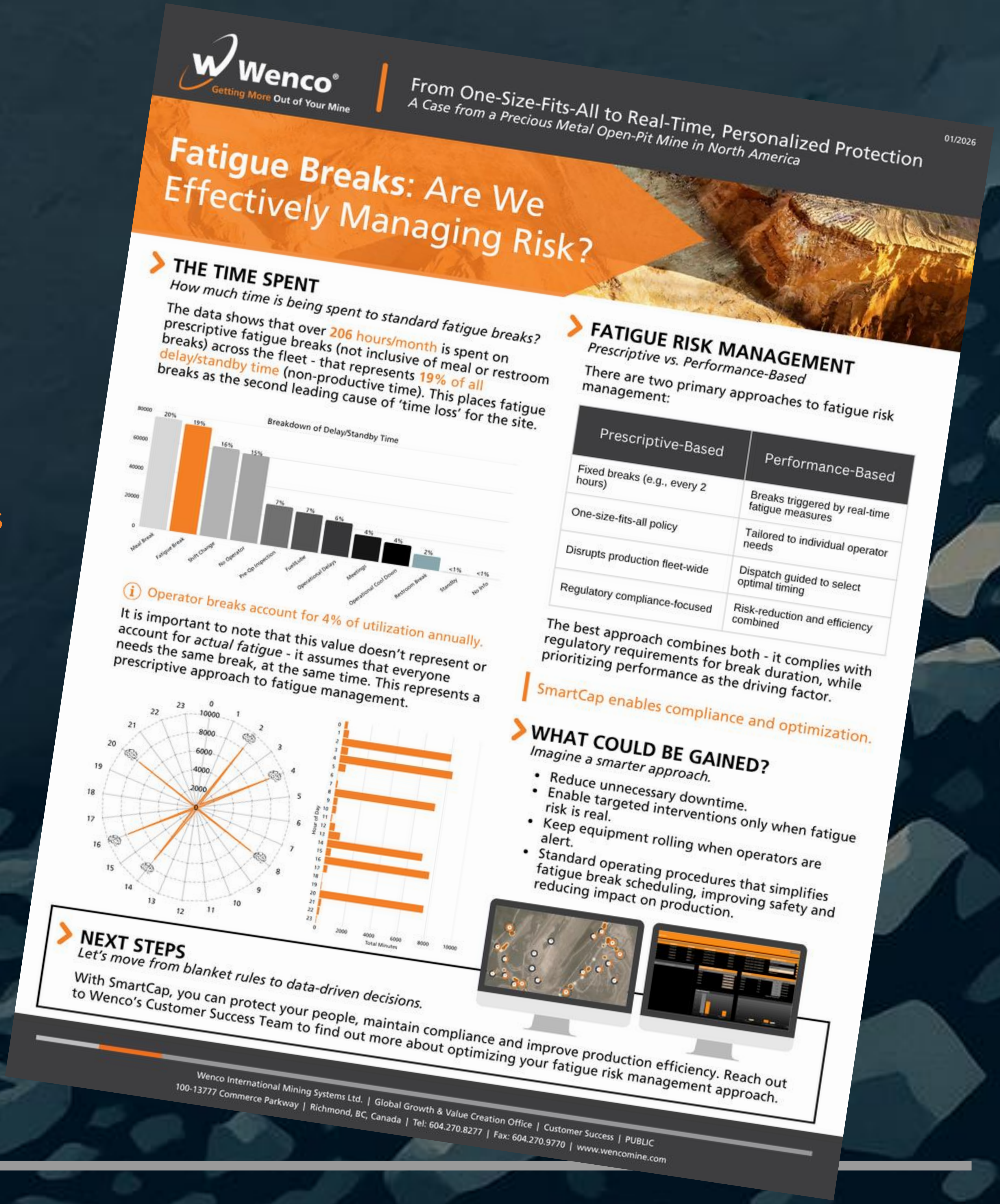
FROM INSIGHT TO ACTION

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

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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.

Breakdown of Delay/Standby Time

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.

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.

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.

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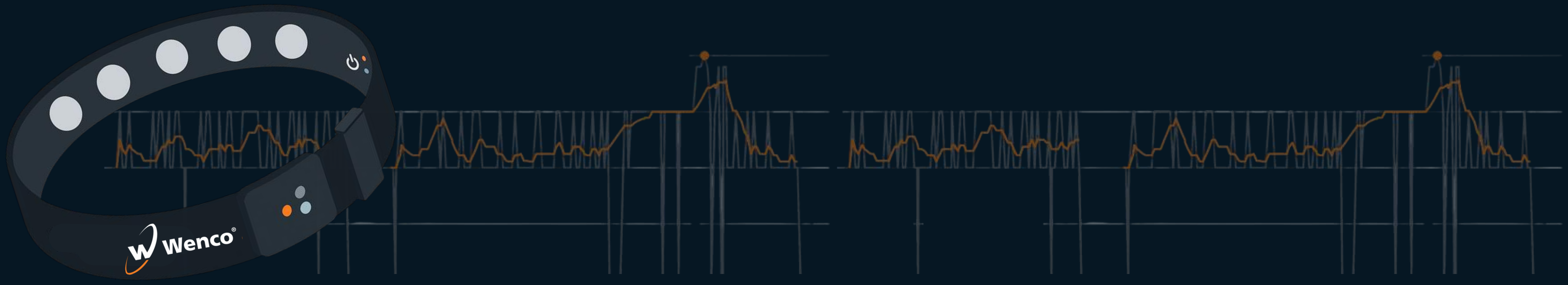
CLOSING MESSAGE

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

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