NAC Executive Insights

Fatigue Risk Index

Key Points

- **Fatigue is a critical, multifactorial risk driver in construction**, shaped by shift patterns, job roles, and environmental conditions, and carrying significant economic and operational consequences.
- **Modeling fatigue as a state variable enables real-time tracking, prediction, and system-level risk assessment**, aligning with complex adaptive systems thinking.
- **The Fatigue Assessment Scale for Construction Workers (FASCW)** provides a low-cost, validated subjective measure of fatigue, though limitations remain.
- **The proposed Fatigue Risk Index (FRI)** offers a more robust, data-driven alternative by converting quantitative fatigue indicators into operational risk indices that support decision-making.
- **Wearables, sensors, and physiological monitoring technologies** now enable objective, real-time fatigue assessment on construction sites.
- **AI/ML (Machine Learning) models and digital twin architectures** represent the next leap in fatigue risk management, enabling predictive analytics, dynamic risk coupling, and integration with BIM/PMS (Project Management Systems) systems.
- **The future of construction fatigue management lies in integrating subjective tools (FASCW), predictive models (FRI), real-time automation, and digital twins** into a unified, adaptive system.

1.0 Introduction

Fatigue is a pervasive and underestimated risk driver across transportation, industry, and construction. National data reveals that more than **6,300 deaths in 2023** were attributable to suspected drowsy-driving crashes, which is nearly **10 times higher** than official federal counts due to chronic underreporting. In the workplace, approximately **37–43% of workers are sleep-deprived**, leading to slower reaction times, impaired decision-making, and elevated incident rates.

The construction industry inherits all these risks while adding unique challenges: long shifts (10–12+ hours), early start times, night work, environmental stressors, and complex, interdependent tasks. Within this context, fatigue acts as a **latent, systemic amplifier** rather than an isolated hazard. This Executive Insight frames fatigue as a **"state variable"**—a continuously changing condition that alters the reliability of every control layer in a project, including human performance and supervisory oversight.

2.0 Fatigue's Impact on Safety

Fatigue's impact is most clearly seen in transportation safety. Suspected drowsy driving deaths in 2023 accounted for approximately **13% of the total economic burden of U.S. traffic crashes**, or roughly **$109 billion annually**. Underreporting is severe because fatigue leaves **no measurable post-crash biomarker**, unlike alcohol or drugs.

2.1 Physiological Impairment Equivalency

Scientific consensus establishes a direct link between hours awake and blood alcohol content (BAC) equivalents:

- **17 hours awake** is approximately equivalent to a **BAC of 0.05**.
- **24 hours awake** is approximately equivalent to a **BAC of 0.10**, which is legally drunk.

2.2 Workplace Patterns

Fatigue-related incidents typically occur during circadian low points: **late night (midnight–6 a.m.)** or **mid-afternoon**. These incidents often involve no braking or evasive action, indicating "microsleep" events where the operator is completely unresponsive. Shift workers face a **6x higher crash risk**, and 62% of night shift workers report significant sleep loss.

3.0 Fatigue in Construction

Construction workers are disproportionately affected by fatigue due to project surges, overtime cycles, and early starts. Fatigued workers are **3 times more likely** to be involved in an incident. Fatigue is a cited factor in:

- **Equipment incidents** (cranes, heavy machinery).
- **Falls** due to reduced balance and attention.
- **Struck-by events** and site logistics vehicle accidents.

3.1 Economic and Productivity Impact

Fatigue costs employers **$1,200–$3,100 per worker annually** in lost productivity. This manifests in three primary ways:

1. **Rework and Quality Defects:** Fatigue degrades fine-motor precision and working memory, leading to incorrect measurements, missed installation steps, and reduced vigilance during inspections. Even moderate sleep restriction can reduce accuracy by **20–50%**.

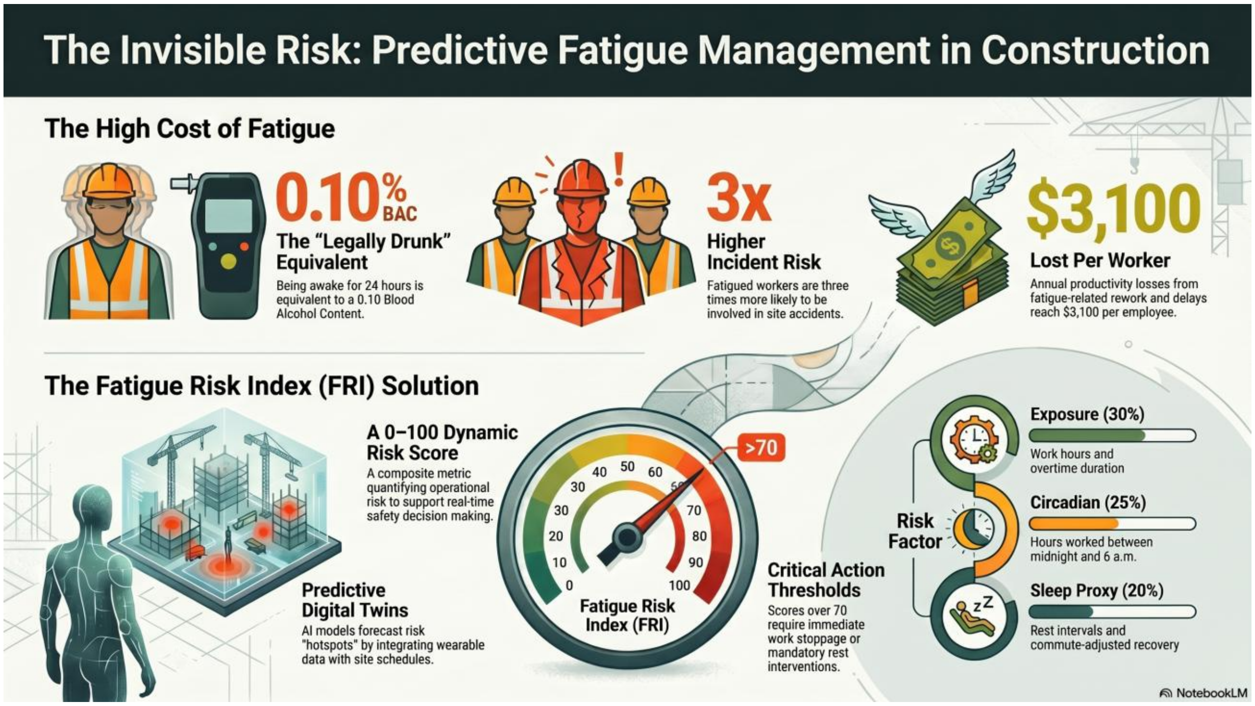
2. **Schedule Slippage:** Fatigue causes slower task execution and increased productivity variability. Because construction trades are interdependent, small fatigue-related slowdowns create cascading delays across the critical path.
3. **Increased Incident Investigation Downtime:** Even low-severity incidents interrupt workflows and consume supervisory bandwidth for root-cause analysis.

3.2 Construction's Overlap with Transportation Risk

A large portion of construction fatalities involve vehicles (both on-site and commuting) with 1 in 5 fatal crashes involving fatigue with early start times plus long shifts contributing to elevated commute-related fatalities.

This creates a compound risk model:

> ***Worker fatigue* → degraded performance on-site → elevated risk during commute → extended fatigue cycle**



4.0 Conceptual Framing: Quantum Project Management (QPM)

Aligning with **Quantum Project Management (QPM)**, fatigue is viewed as a **nonlinear risk amplifier**. It shifts the entire project into a higher-risk regime by degrading human reliability and decision quality simultaneously.

5.0 Operationalizing Fatigue as a Measurable Risk Variable

To move toward predictive control, organizations must track leading indicators that are observable in real-time.

5.1 Core Fatigue Exposure Metrics

- **Work Duration:** Shifts >10 hours indicate elevated risk; >12 hours indicate high risk.
- **Circadian Disruption:** Percentage of hours worked between midnight and 6 a.m. and the frequency of night shifts.
- **Sleep Opportunity Proxies:** Measuring the minimum rest period between shifts and **commute-adjusted rest time** (time off minus commute and personal needs). Less than **7 hours of effective rest** results in a high fatigue probability.

5.2 Behavioral and Performance Signals

Fatigue manifests as increased variability in performance, "simple mistakes," higher near-miss rates, and procedural deviations. Supervisors can convert observations into data by tracking "fatigue flags" like yawning, slowed response, or "zoning out".

5.3 Task and Environment Multipliers

Risk is adjusted based on exposure to high-risk tasks (heavy equipment, work at height) and **environmental load** (heat index/WBGT). Notably, **heat + fatigue creates multiplicative risk**, not just additive.

6.0 Fatigue Risk Index (FRI) – A Composite Metric

The FRI is a 0–100 dynamic score that quantifies operational risk.

6.1 Comparing FASCW and FRI

- **FASCW (Subjective):** A validated 10-item self-report scale measuring **Lethargy** and **Bodily Ailment**. It is simple and captures internal states but is subject to reporting bias.
- **FRI (Objective):** A system-level metric integrating data on hours, rest, and behavior. It is data-driven and supports predictive analytics but requires more infrastructure to implement.

6.2 The FRI Formula and Weights

The proposed formula is: **FRI = 100 X (0.30 E + 0.25 C + 0.20 S + 0.15 B + 0.10 T)**

- **E (Exposure - 30%):** Strongest predictor; includes work hours and overtime.
- **C (Circadian - 25%):** Major driver of microsleeps and severe incidents.
- **S (Sleep Proxy - 20%):** Measurable via rest intervals and commute-adjusted rest.
- **B (Behavioral - 15%):** Early symptoms used for calibration.
- **T (Task/Environment - 10%):** Amplifies consequences.

6.3 Action Thresholds

- **FRI < 30:** Normal operations.
- **FRI 30–50 (Elevated):** Increase supervision and add micro-breaks.
- **FRI 50–70 (High):** Restrict high-risk tasks and adjust shifts.
- **FRI > 70 (Critical):** Stop or rescope work; mandatory rest interventions.

7.0 Dynamic and Adaptive Extensions

In complex systems, risk emerges from interactions. The FRI can be extended with **nonlinear triggers**: if a rising FRI coincides with rising heat, a multiplier (e.g., x1.2) is applied. It also tracks **entanglement**, such as the correlation between fatigue and schedule pressure or safety compliance drift.

7.1 Minimal Viable Implementation

Organizations can start by tracking just five metrics: **shift length, rest intervals, self-reported fatigue, near-misses, and high-risk task exposure**. This creates a weekly FRI dashboard that can be calibrated over time.

Minimal Viable Implementation

A "Minimal Viable Implementation" providing a quick practical start involves tracking just:

- *Shift length*
- *Rest interval*
- *Self-reported fatigue*
- *Near-misses*
- *High-risk task exposure*

8.0 Tools, Technologies, and Data Sources

8.1 Existing Biomathematical Models

Tools like **SAFTE-FAST** and the **HSE Fatigue and Risk Index** predict alertness based on sleep and work data, though they often require adaptation for construction.

8.2 Wearable Technologies

Modern devices provide objective physiological data that correlates with fatigue states:

- **HRV (Heart Rate Variability) Monitors:** Low HRV correlates with lethargy.
- **EMG (Electromyography):** Monitor muscle activation and fatigue.

- **IMUs (Inertial Measurement Unit)/Accelerometers:** Track step count, posture, and gait speed; slower movement reflects lethargy.
- **EEG (Electroenphalogram) Headbands:** Detect brain wave patterns (theta/alpha shifts) correlating with mental fatigue.

8.3 Digital Twin Predictive Modeling

A **Digital Twin** is a virtual mirror of the construction site fed by real-time data. It uses machine learning to forecast when and where the risk landscape will shift into a higher-risk regime, allowing leaders to **anticipate and defuse** risks before they escalate.

8.4 Functional Readiness Assessments

Fatigue can be inferred through pre-shift tests such as **grip strength**, **timed sit-to-stand tests**, or **cognitive reaction tests** on tablets. These surrogates help estimate FASCW scores objectively.

8.5 Fatigue Assessment Scale for Construcion Workers (FASCW) Survey and Scoring

The FASCW uses a 10-item survey (rated 1-5) to assess fatigue:

1. Mental Drain - Physically drained during shift
2. Energy Drop - Trouble staying mentally sharp.
3. Slow Decisions - Worn out before shift ends.
4. Low Drive - Extra effort to concentrate.
5. Worn Down - Needing to re-check work more often.
6. Heavy Body - Losing track of tasks.
7. Muscle Tightness - Less motivated than normal.
8. Physical Strain - More irritable or frustrated.
9. Aches/Disconfort - Not fully recovered at start of shift.
10. Physical Exhaustion - Tired even after a full night’s sleep.

Interpretation: Scores of **30–39** indicate high, safety-relevant fatigue; **40–50** represent critical concerns requiring immediate stop-work conversations.

9.0 Conclusion

Fatigue in construction is not a peripheral concern—it is a **system-shaping force** that alters human performance, supervisory effectiveness, and the stability of project operations. As shown throughout this Executive Insight, fatigue behaves as a **state variable**, one that “*changes the reliability of every other control system*” and “*shifts the entire project into a higher-risk regime*”. The evidence is clear: fatigue is widespread, underreported, and deeply intertwined with schedule design, environmental stressors, and the physical and cognitive demands of construction work.

Traditional approaches—reactive incident investigation, generic toolbox talks, or broad wellness messaging—are insufficient for the complexity and scale of modern construction. The industry now has the opportunity to adopt **quantitative, predictive, and adaptive fatigue-management systems** that match the realities of large, interdependent, time-compressed projects.

ANALOGY – Fatigue on an Athlete and Construction Industy Worker
Fatigue severly degrades athletic performance, reducing strength, endurance and reaction times. It impairs tactical decision-making, technical execution and diminishes overall motivation. The same is true for the construction industry impacting directly on worksite productivity and an increase in workplace accidents.

9.1 From FASCW to FRI: Evolving from Measurement to Prediction

The **Fatigue Assessment Scale for Construction Workers (FASCW)** provides a validated, worker-centered measure of fatigue severity. It remains essential because it captures **subjective experience**, which no sensor or algorithm can fully replace. However, FASCW alone cannot anticipate when fatigue will emerge or how it will interact with schedule pressure and high-risk tasks.

This is where the **Fatigue Risk Index (FRI)** provides a decisive advantage. By combining exposure metrics, circadian disruption, sleep proxies, behavioral indicators, and environmental multipliers into a **0–100 dynamic score**, the FRI transforms fatigue into a **leading, predictive, and actionable risk variable**. It enables project teams to adjust sequencing and staffing before fatigue reaches critical thresholds.

9.2 Automation and the Digital Twin: The Next Frontier

Automation is the enabler for modern fatigue management, enhancing the system in three ways:

1. **Real-time data capture:** Wearables and cognitive microtests provide continuous streams of objective data.
2. **Continuous risk scoring:** Automated ingestion allows the FRI to update dynamically without manual intervention.

3. **Predictive modeling through the Digital Twin:** Machine-learning models forecast emerging hotspots and simulate the impact of schedule or weather changes.

This creates a **closed-loop system**: Data → FRI scoring → Digital Twin prediction → Action Engine → Field adjustments → New data.

9.3 Industry Recommendations

Construction leaders should:

- Deploy **FASCW** as a baseline subjective tool.
- Track the **Minimal Viable Implementation** metrics immediately.
- Implement the **FRI** to provide unified quantitative scores.
- Integrate **wearables** for objective detection.
- Build toward **Digital Twin deployment** for proactive scenario planning.

The table below provides a concise set of recommendations for construction leaders, safety professionals, and project executives seeking to operationalize fatigue as a measurable, predictive risk variable.

Recommendations for Implementing Predictive Fatigue Management in Construction		
Category	**Recommendation**	**Purpose / Benefit**
Foundational Assessment	Deploy FASCW as a baseline and periodic self-report tool.	Captures subjective fatigue dimensions (lethargy, bodily strain) that sensors cannot detect.
Core Metrics	Track the five "Minimal Viable Implementation" metrics: shift length, rest interval, self-reported fatigue, near misses, high-risk task exposure.	Establishes a simple, scalable starting point for fatigue monitoring.
Composite Risk Scoring	Implement the Fatigue Risk Index (FRI) using exposure, circadian, sleep-proxy, behavioral, and task/environment inputs.	Provides a unified, quantitative fatigue score with actionable thresholds.
Schedule Integration	Use FRI trends to adjust work sequencing, shift design, and crew rotation.	Reduces schedule-driven fatigue amplification and prevents cascading delays.
Automation & Wearables	Integrate HRV monitors, IMUs, cognitive micro-tests, and activity sensors.	Enables continuous, objective fatigue detection and early warning signals.

Recommendations for Implementing Predictive Fatigue Management in Construction		
Category	**Recommendation**	**Purpose / Benefit**
Digital Twin Deployment	Build a predictive fatigue model that simulates future fatigue states based on planned work, weather, and staffing.	Allows proactive mitigation and scenario planning before risk emerges.
Dynamic Thresholds	Apply nonlinear triggers (e.g., heat × long shifts) and entanglement mapping (fatigue × schedule pressure).	Reflects real-world complexity and prevents underestimation of compound risks.
Operational Response	Link FRI thresholds to predefined actions (e.g., micro-breaks, task restrictions, relief crews).	Ensures consistent, timely interventions aligned with risk level.
Continuous Learning	Use feedback loops to recalibrate thresholds based on project-specific incident and performance data.	Improves accuracy and tailors the system to each project's unique conditions.

9.4 Closing Perspective

Fatigue is a **systemic performance variable** that shapes safety, productivity, and schedule reliability. This shift recognizes construction as a complex and dynamic system and aligns directly with the principles of **Quantum Project Management**, where uncertainty, emergence, and entanglement are treated as design parameters. When fatigue is managed as a measurable, dynamic state variable, project leaders gain the ability to **anticipate risk, optimize schedules, and protect their workforce** with unprecedented precision.

10.0 For Further Reading - Other Executive Insights

- Fragility
- Uncertainty Assessment
- Safety Degradation Risk Index (SDRI): The Link Between Safety and Profitability
- Human Factors in Large Complex Projects
- Project Planning
- Out of Sequence Construction
- Barriers to Productivity – An Overview

11.0 Other Reading

Prieto, R. (2026). Fatigue Risk Index: Measuring an "Internality" as a Performance Precursor Under Quantum Project Management (QPM) Theory, PM World Journal, Vol. XV, Issue VI, June. (PDF) Fatigue Risk Index: Measuring an "Internality" as a Performance Precursor Under Quantum Project Management (QPM) Theory

About the Authors

Bob Prieto was elected to the National Academy of Construction in 2011. He is a senior executive who is effective in shaping and executing business strategy and a recognized leader within the infrastructure, engineering, and construction industries. Bob received the 2024 ASCE OPAL Award (Outstanding Projects and Leaders) for his Outstanding Lifetime Achievement in Management.

Jerry Eyink was elected to the National Academy of Construction (NAC) in 2011. He spent his working career with Anheuser-Busch Inc., retiring as the Group Director—Project Management and Planning for the Engineering Group. He received his engineering degree from Purdue University and his MBA from Saint Louis University. The Academy honored him with its Richard L. Tucker Outstanding Service Award in 2022 for his continuous support to NAC.