Quest global

Redefining Asset Integrity Through Expert-in-the-Loop AI

A Framework for IOW Management in Oil Refineries

The Silent Crisis in Our Control Rooms

Every morning, thousands of experienced operators across oil and gas refineries make decisions that keep the energy infrastructure running safely and efficiently. These aren't just operational choices, they're the culmination of decades of hard-earned expertise that simply cannot be found in any manual or training program. But this irreplaceable expertise is leaving faster than companies can replace it.

According to the U.S. Bureau of Labor Statistics, there were 119,000 workers in the oil and gas industry as of February 2024, a steady decline from the 195,000 workers 10 years ago, a staggering 39% workforce reduction. This isn't just a numbers game; it's a fundamental threat to operational continuity that has been decades in the making.

The Great Retirement Wave

Industry data reveals that over 50% of the current workforce is aged 45 or older, with many occupying critical technical and leadership positions. In key regions across North America and Europe, up to 25% of employees are expected to retire within the next five to ten years. These aren't entry-level positions, these are the geoscientists who understand reservoir behavior, the engineers who can diagnose equipment issues by subtle changes in vibration patterns, and the operations managers who've navigated every conceivable crisis scenario.

When these professionals retire, they take with them an irreplaceable library of experience. They understand the subtle interactions between process variables that textbooks never capture. They know which alarms typically resolve themselves and which ones demand immediate attention. They've developed an intuitive sense for their equipment's behavior patterns that comes only from years of hands-on experience.

The Challenge of Attracting New Talent

Simultaneously, attracting younger professionals has become increasingly difficult. The perception challenge represents perhaps the most significant barrier. Many young professionals view the industry through the lens of environmental concerns, seeing oil and gas as outdated compared to renewable energy sectors. Educational institutions have responded by reducing focus on petroleum engineering and geosciences programs. Universities that once produced dozens of petroleum engineers annually now graduate single-digit numbers, creating a supply-demand imbalance that shows no signs of resolving quickly.

- The cyclical nature of oil prices, combined with growing regulatory pressures, has made the sector appear unstable to potential job seekers. According to recent analysis, the energy industry could face a shortage of up to 40,000 skilled workers by 2025. Companies now compete for talent not just with other oil and gas firms, but with entire industries offering similar technical challenges alongside different risk profiles and growth narratives.
- This combination of accelerating retirements and insufficient new talent influx is creating what can only be described as a capability cliff. Without strategic intervention, many refineries risk experiencing a sharp decline in operational capability over the coming decade.

Understanding Integrity Operating Windows

In the complex orchestration of refinery operations, Integrity Operating Windows (IOWs) represent one of the most critical defense mechanisms against equipment failure and loss of containment incidents. Yet for many in our industry, IOWs remain somewhat abstract, a compliance requirement rather than the vital operational tool they were designed to be.

IOWs are established limits for key process variables that can affect equipment integrity if operations deviate from established boundaries. Think of IOWs as the guardrails that keep our operations within the safe envelope where equipment can function reliably over its intended lifespan.

The Science Behind IOWs

IOWs are fundamentally rooted in materials science and degradation mechanisms. Every piece of equipment operates within specific material limits. These include temperature ranges where metallurgy remains stable, pressure boundaries that prevent fatigue cracking, chemical concentration limits that avoid accelerated corrosion, and flow parameters that minimize erosion. For instance, a heat exchanger's IOW might include temperature limits to prevent thermal stress cracking, pressure differentials to avoid tube sheet fatigue, and flow rates to minimize erosion-corrosion. A distillation column's IOWs might encompass temperature profiles to prevent differential thermal expansion issues and chemical concentration boundaries to minimize acid corrosion.

The Two-Tier Framework

Modern IOW implementation typically follows a two-tier structure:

Tier 1 Limits represent the absolute boundaries—the red lines that cannot be crossed without immediate risk of equipment damage. Violation of Tier 1 IOWs typically triggers automatic responses or requires immediate operator intervention.

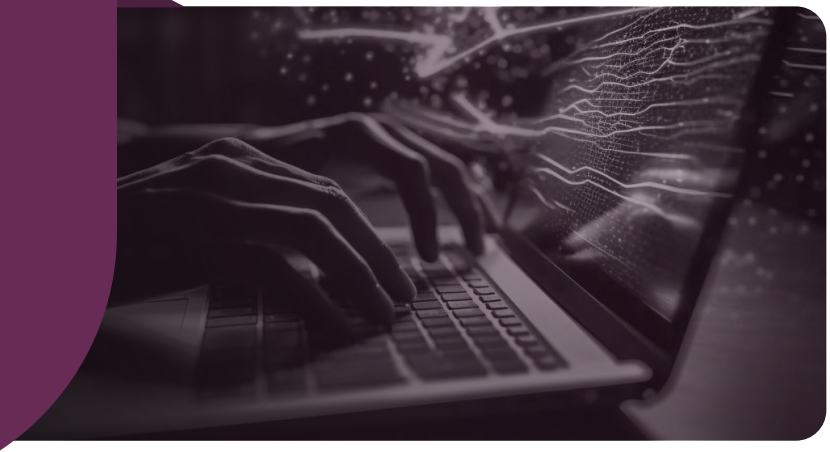
Tier 2 Limits serve as early warning systems, providing advance notice when operations are drifting toward Tier 1 boundaries. These limits give operators time to investigate root causes and implement corrective actions before situations become urgent.

The Human Element in IOW Management

Here's where the challenge becomes apparent. IOWs generate enormous amounts of data and alarms, but their effectiveness depends entirely on human interpretation and response. An experienced operator doesn't just see that a temperature has exceeded a Tier 2 limit. They understand what that means in the context of current weather conditions, recent maintenance activities, feed quality changes, and dozens of other variables. They know which combinations of parameter deviations are benign and which represent genuine threats. They understand the sequence of actions most likely to restore stability quickly and safely. Most importantly, they can distinguish between symptoms and root causes.

This is the knowledge that retires with the senior staff, and it's precisely what needs to be preserved and transferred to the next generation of operators.

The Digital Systems in Modern Refineries



Modern refinery control rooms feature sophisticated ecosystems of digital systems that collect, process, and present thousands of data points every second. Understanding this digital landscape is crucial because it forms the foundation upon which Expert-in-the-Loop AI systems operate.

Process Historians and Data Infrastructure

At the heart of most refinery digital ecosystems sits the PI System (OSIsoft PI Historian), which serves as the facility's long-term memory. This real-time data infrastructure continuously collects, stores, and contextualizes time-series process data from thousands of measurement points throughout the facility. Every temperature, pressure, flow rate, level, and analytical result becomes part of a historical record. The PI System enables sophisticated trend analysis, allowing operators to understand how current conditions compare to historical patterns.

The challenge lies in interpretation of this vast dataset. An experienced operator can look at trending data and immediately recognize patterns that suggest impending equipment issues. A less experienced operator might see the same data but miss the subtle indicators that require attention.

Asset Performance Management Systems

GE APM (Asset Performance Management) and similar platforms represent the evolution from reactive to predictive maintenance strategies. These systems integrate process data with equipment design specifications, maintenance history, and degradation models to provide insights into asset health and performance trends. APM systems excel at identifying early indicators of equipment degradation and can model the impact of different operating strategies on equipment life. Integration with IOW frameworks allows these systems to understand how operating parameter deviations affect long-term equipment integrity.

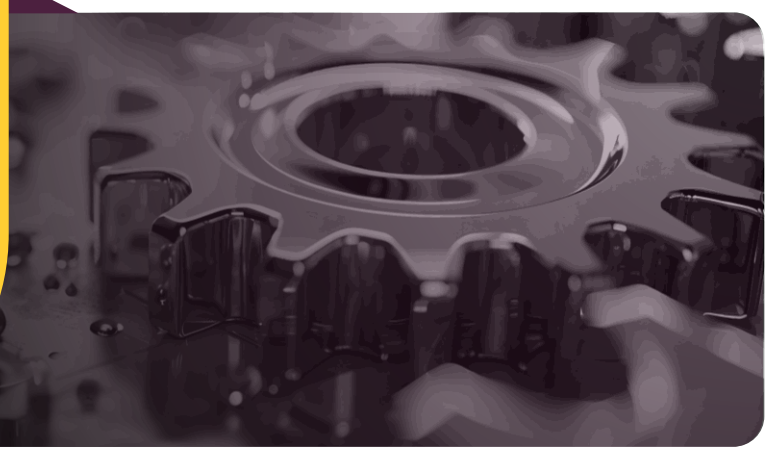
Control and Monitoring Systems

01 **Distributed Control Systems (DCS)** from vendors like Honeywell, Emerson, Yokogawa, and ABB serve as the primary interface between operators and refinery processes. These systems control real-time operations while providing the human-machine interface through which operators monitor and adjust operations.

02 **SCADA (Supervisory Control and Data Acquisition)** systems complement DCS platforms by providing higher-level visibility across multiple units or entire facilities, enabling remote monitoring and coordination of responses to complex incidents.

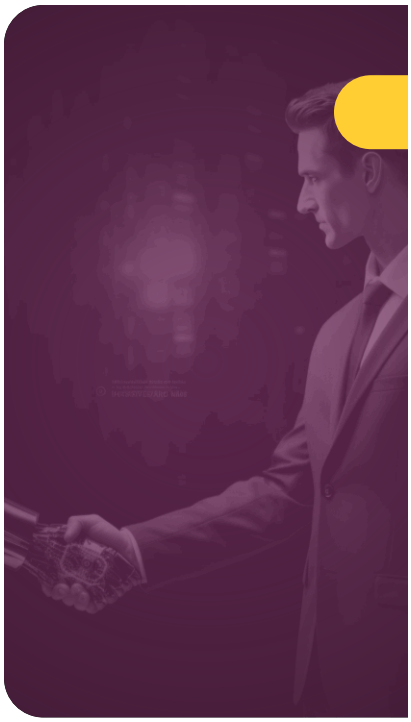
03 **CMMS (Computerized Maintenance Management Systems)** like IBM Maximo and SAP PM manage maintenance activities, while **LIMS (Laboratory Information Management Systems)** ensure product quality and process specifications remain within required limits.

The Integration Challenge



While each system excels in its specific domain, the real value emerges from their integration. Modern refineries generate enormous amounts of data across all these platforms, but transforming that data into actionable insights requires sophisticated analysis and experienced interpretation. Senior operators don't just understand individual systems, they understand how information from multiple systems combines to paint a complete picture of facility operations. The question becomes how do we capture and transfer this integrative knowledge to less experienced operators who haven't had years to develop this systems-thinking capability.

Expert-in-the-Loop AI as a Partnership Approach



Although the idea of artificial intelligence in industrial operations often raises fears that automation will supplant human judgment, Expert-in-the-Loop (EITL) AI takes a fundamentally different route, one that preserves human authority while amplifying capability. Rather than replacing operators, EITL AI builds a digital apprenticeship system that captures, preserves, and shares the decision-making patterns of our most experienced professionals. Picture a senior operator standing behind every control-room desk, offering guidance drawn from decades of real-world scenarios.

The Learning Partnership Model

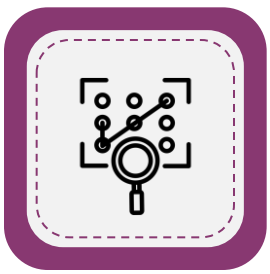
At its core, EITL AI observes human decision-making patterns without ever making autonomous decisions. When an IOW alarm triggers, experienced operators evaluate multiple factors: current process conditions, recent operational changes, weather patterns, equipment maintenance history, and dozens of other variables. The AI system observes these decisions, notes the contextual factors, and tracks the outcomes. Over time, the system builds holistic understanding of how experienced operators respond to different combinations of conditions. This learning process reveals that certain IOW violations during summer heat waves require different responses than the same violations during winter operations. The system recognizes that alarms occurring shortly after maintenance activities often have different root causes than those during steady-state operations.

This learning process is continuous and adaptive. As operators refine their approaches based on new experience, the AI system updates its understanding accordingly. The result is a decision support system that reflects current best practices rather than outdated procedures.

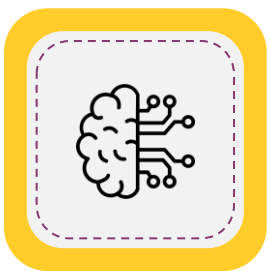
Applications in IOW Management

Alarm Prioritization: EITL AI systems learn from expert responses to different types of alarms, understanding which combinations of factors indicate true urgency versus temporary upsets that will self-correct or respond to routine adjustments.

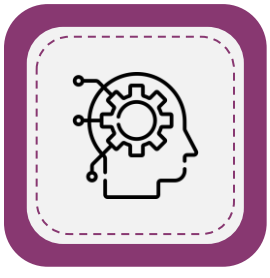
Action Recommendation: When IOW violations occur, EITL AI can suggest specific sequences of actions based on what has proven most effective in similar situations, including the timing and magnitude of adjustments that typically restore stable operations most quickly.



Pattern Recognition: Experienced operators often recognize subtle patterns that precede IOW violations. EITL AI can learn these patterns and provide early warnings, giving operators time to address root causes before alarms actually trigger.



Root Cause Learning: The AI system can connect short-term responses with long-term outcomes, identifying which types of IOW violations tend to recur if addressed only symptomatically versus those that respond well to immediate corrective action.



Continuous Learning: AI updates its model based on operator actions and results, improving recommendation quality over time while adapting to changing equipment conditions and operational strategies.

Supporting Junior Staff Development

One of the most significant benefits lies in accelerating the development of less experienced operators. EITL AI can provide contextual decision support that mimics the mentoring relationship with senior operators. When facing an unfamiliar situation, a junior operator can receive guidance that reflects the collective wisdom of multiple senior operators across many similar incidents.

The system can explain why certain actions are recommended, what outcomes to expect, and what warning signs to monitor. This doesn't replace human mentorship, but it extends the reach of experienced operators beyond their immediate presence.

The Business Case for EITL AI Implementation

The return on investment for EITL AI implementation becomes apparent across multiple dimensions of refinery operations, contributing to both immediate operational improvements and long-term strategic value creation.

Reducing Unplanned Downtime

Unplanned shutdowns represent one of the most significant cost drivers in refinery operations. Depending on unit complexity and market conditions, each event can cost between **$250,000 and $1 million** in lost production, emergency maintenance costs, and restart expenses. EITL AI systems demonstrate particular value in preventing these costly events by enabling more effective early intervention. When IOW violations occur, the difference between an experienced operator's response and an inexperienced operator's response often determines whether the situation stabilizes quickly or escalates into a unit trip.

Early implementation results suggest that facilities can reduce unplanned shutdown frequency by **15-25%** through more effective IOW violation management, translating to millions of dollars in avoided costs for larger facilities.

Improving Asset Utilization

Refineries often operate conservatively when staffed with less experienced personnel, maintaining larger safety margins to compensate for uncertainty about equipment limits. EITL AI systems enable more aggressive optimization by providing operators with confidence about equipment limits and appropriate responses. Industry experience suggests that facilities implementing EITL AI support can achieve **2-5% improvements in throughput** by reducing conservative operating margins. For a medium-sized refinery processing 100,000 barrels per day, this translates to 2,000-5,000 additional barrels of daily capacity.

Optimizing Expert Resources

Senior operators represent one of the most valuable and scarce resources in modern refineries. EITL AI systems can dramatically improve how these experts spend their time by reducing routine consultations and enabling focus on truly complex problems.

Facilities typically find that 40-60% of senior operator time involves providing guidance on routine IOW management decisions. EITL AI can address many of these routine needs, effectively multiplying the impact of scarce expert resources.

Accelerating Training and Development

Traditional operator training programs require extensive time investments. New operators typically require 12-18 months of supervised experience before they can handle complex IOW situations independently. EITL AI can significantly accelerate this learning process.

Facilities implementing EITL AI support typically report **20-30% reductions** in the time required for new operators to achieve independent competency levels, translating to both direct training cost savings and indirect benefits from having more capable operators available sooner.

Economic Impact Summary

Benefit Area	Value Creation
Reduced Unplanned Downtime	Savings of $250K-$1M per avoided event
Improved Asset Utilization	2-5% increase in throughput
Reduced Expert Time on Routine Decisions	40-60% of senior operator time freed for strategic work
Training Acceleration	20-30% reduction in time to competency
Fewer Critical Failures	Up to 20-30% reduction in equipment failures

Estimated ROI: *3x-10x in the first 12-24 months, depending on scale and integration depth.*

Implementation Framework

Success in implementing EITL AI for IOW management requires thoughtful planning, stakeholder alignment, and recognition that success depends as much on change management as on technology deployment.

Building the Foundation

Before any AI system can deliver value, the underlying data infrastructure must be robust and reliable. Most refineries already possess sophisticated digital systems, but EITL AI implementation requires these systems to work together smoothly. The first step involves conducting thorough assessment of data quality and availability. IOW management requires accurate, real-time access to process parameters, alarm histories, operator actions, and outcome data. Missing or unreliable data streams can severely compromise AI system effectiveness.

Integration challenges often prove more complex than anticipated. EITL AI systems must pull data from multiple sources—process historians, maintenance systems, laboratory systems, and operator logbooks. Creating reliable, secure data pipelines requires careful technical planning.

Change Management

Technology implementation succeeds or fails based on human acceptance. In refinery environments, where safety depends on proven procedures, introducing AI-based decision support requires careful change management. Senior operators, whose knowledge forms the foundation of EITL AI systems, must understand that they're not being replaced but rather amplified. Their expertise becomes more valuable as it enables less experienced colleagues to operate more effectively. Engaging these experts as partners in system development creates advocates who drive broader organizational acceptance.

Phased Implementation

Successful implementations typically follow a phased approach that builds confidence progressively. Rather than attempting to address all IOW management challenges simultaneously, focusing on specific high-impact areas allows for learning and refinement. Phase one often concentrates on a single critical unit where experienced operators are approaching retirement and IOW violations have historically been challenging. This focused approach allows refinement of data integration processes and validation of AI recommendations.

Phase two expansion addresses additional process units or extends existing implementations to cover more IOW scenarios. Phase three involves facility-wide deployment and integration with broader operational excellence initiatives.

Measuring Success

Defining appropriate success metrics requires balancing quantitative operational improvements with qualitative measures of operator confidence and decision-making effectiveness. Leading indicators, such as the time required for operators to diagnose IOW violations, the consistency of responses across shifts, and the frequency of expert consultations, often prove more valuable than lagging indicators for assessing effectiveness.

Why Global Oil and Gas Leaders Choose Quest Global

Quest Global delivers Expert-in-the-Loop AI that preserves operational expertise. These intelligent systems capture critical decision-making patterns of experienced operators reinforcing human insight. With deep industry-specific expertise, we integrate complex industrial data sources and develop AI models that learn from seasoned operators. This approach delivers proven value - achieving a 25–40% reduction in equipment failures, a 60–70% drop in false alarms, and 50% faster development of new operators. Our scalable solutions start with single-asset implementations achieving positive ROI within 18-24 months, expanding to facility-wide deployments generating $15-30M in annual compound savings. Global oil and gas leaders choose Quest Global because we create AI systems that embody operator wisdom, delivering sustainable competitive advantages that strengthen operational excellence over time.

Preserving Knowledge, Capability, and Continuity

As we navigate the largest workforce transition in our industry's history, Expert-in-the-Loop AI for IOW management offers more than just a technological solution. This approach provides a strategic framework for preserving institutional knowledge, enhancing human capability, and ensuring operational continuity.

This isn't about replacing human judgment with automated decision-making. It's about creating intelligent partnerships that amplify human expertise and make it available to every operator, every shift, every day.

Thank You