An Integrated Framework for Enhancing Nuclear Power Plant Management Performance in the Digital Era

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This framework is based on the review paper:
"Managing Nuclear as an Engineered System: A Review of Safety Culture, Standards-to-Controls, and Quantitative Governance (1979–2024)"

The Core Challenge: A Dual Imperative

1. Unwavering Safety & Public Trust

The non-negotiable foundation of our license to operate.

2. Operational & Economic Excellence

The necessity to compete in complex, deregulated energy markets.

The question is no longer *either/or*. It is both/and.

Our Guiding Question

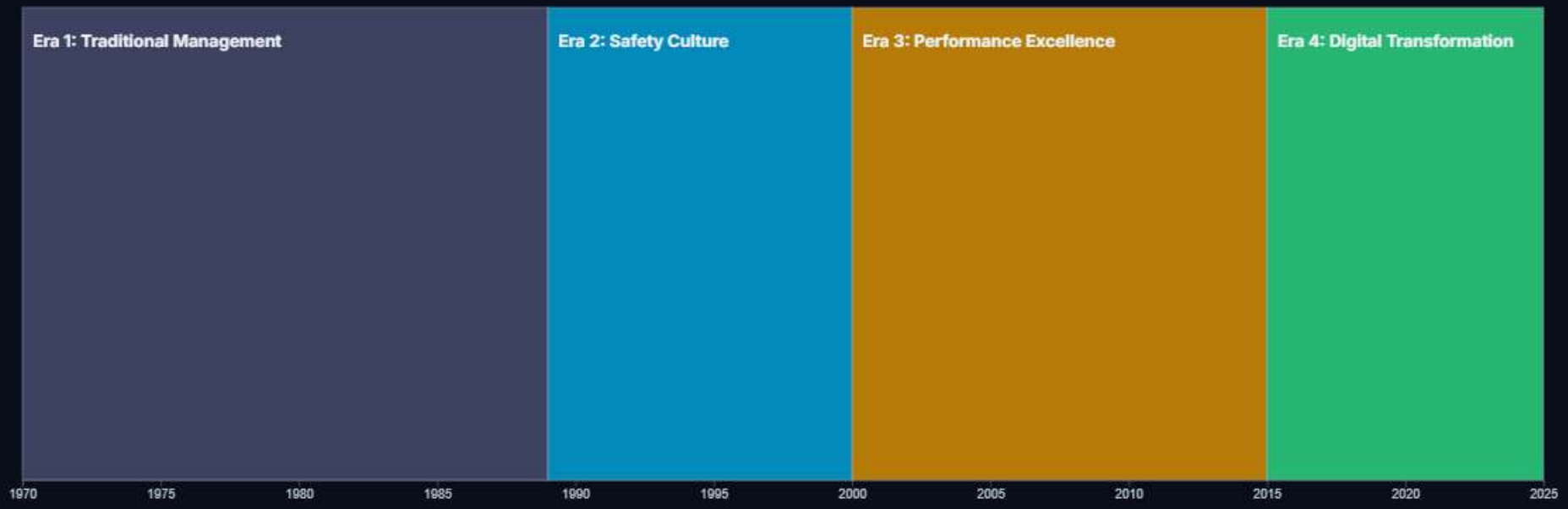
How do we achieve this dual imperative?

> To understand where we are going, we must first understand **how we got here.**

This presentation analyzes the **evolution of NPP management** to build a strategic framework for the future.

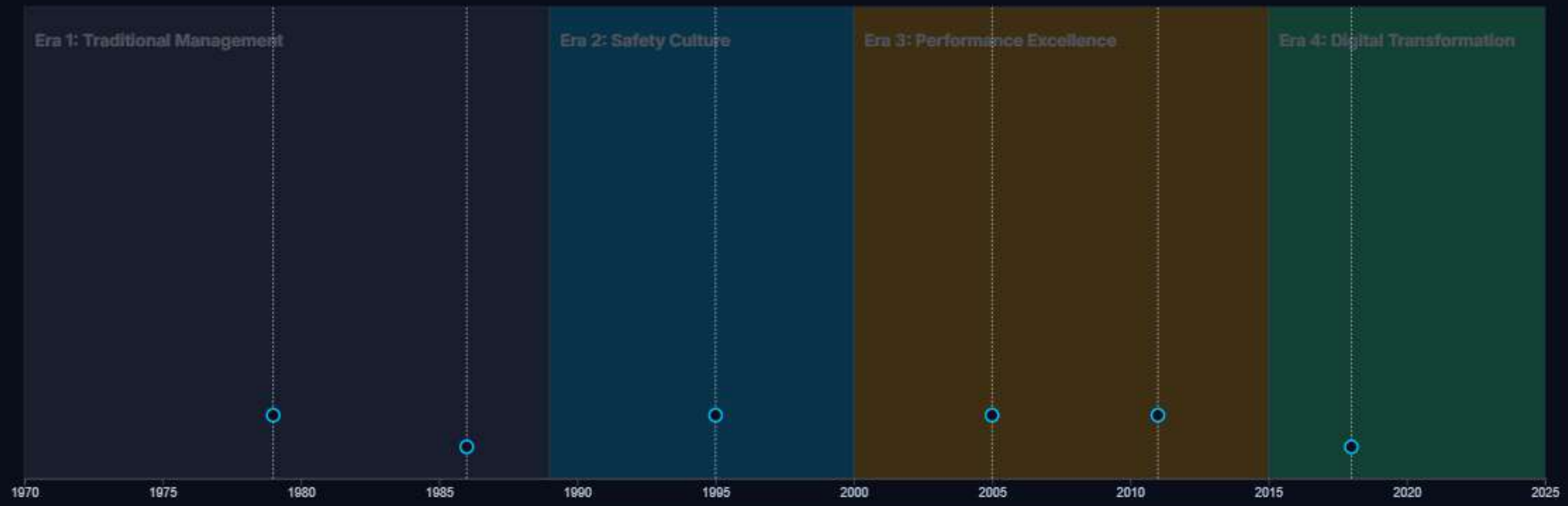
The Evolution of NPP Management

Part 1: The Four Eras



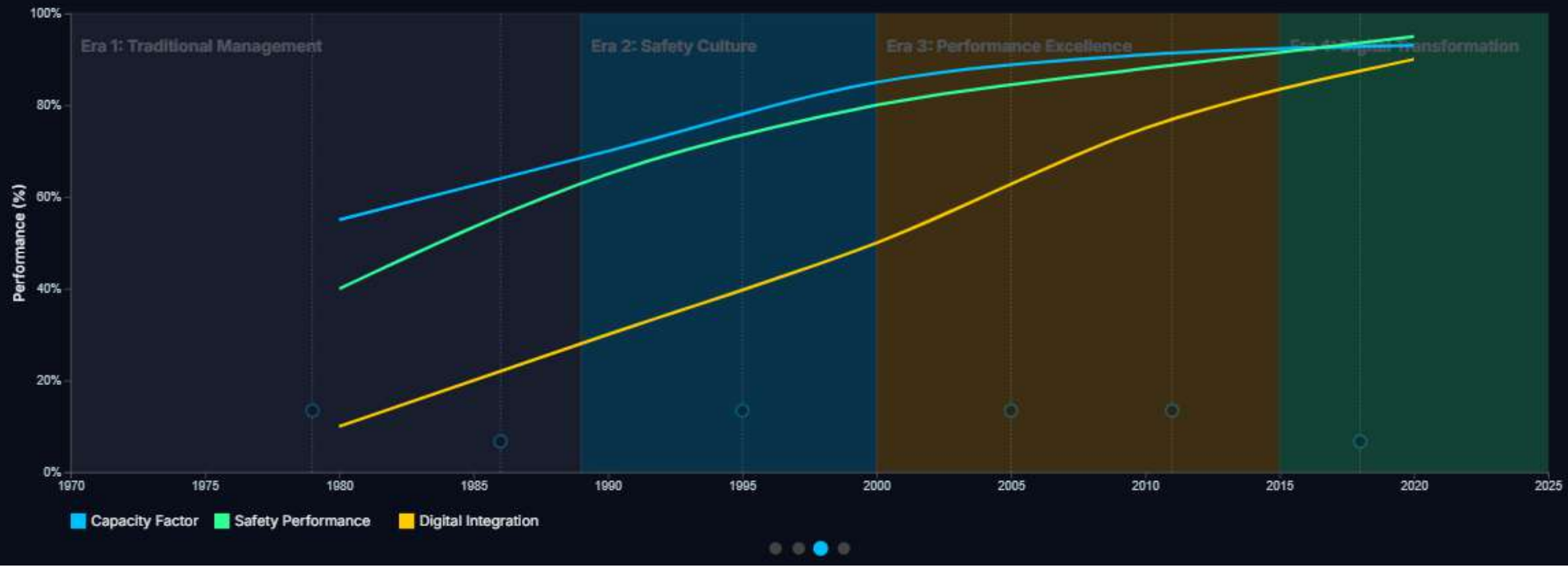
The Evolution of NPP Management

Part 2: Key Milestones (Hover circles)



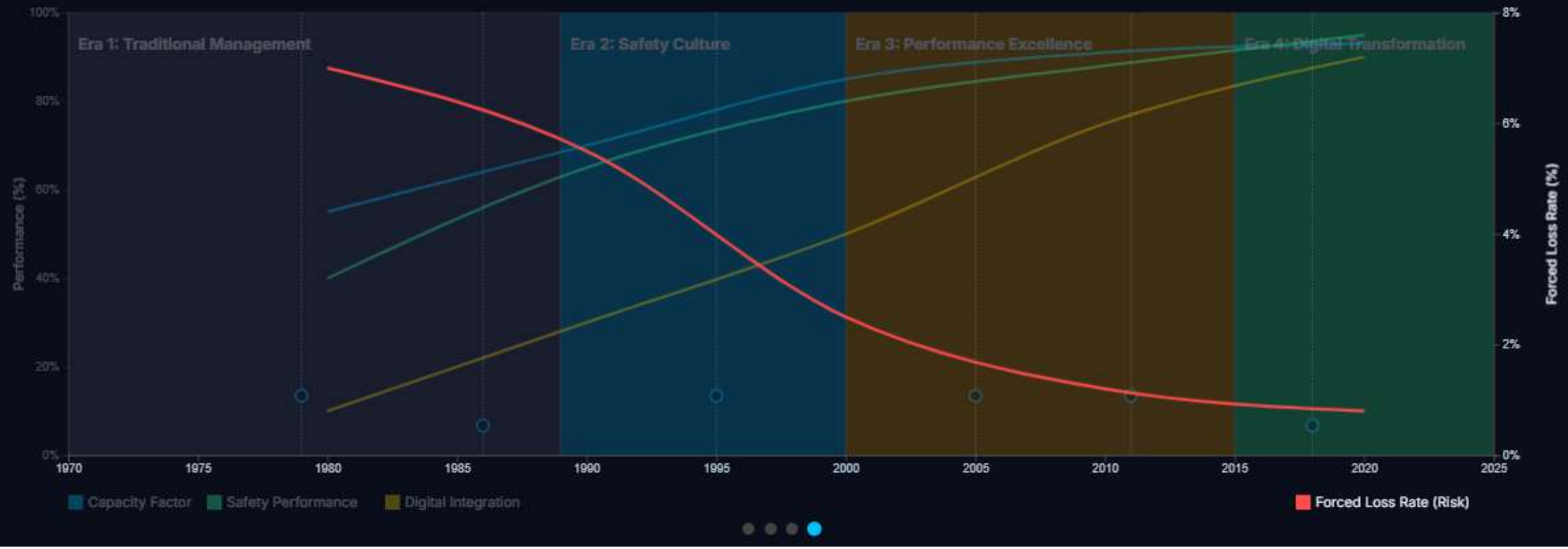
The Evolution of NPP Management

Part 3: Performance & Integration Gains



The Evolution of NPP Management

Part 4: The Full Picture (Performance vs. Risk)



Analysis: Building the "What" and the "Who"

Era 1: Traditional Management (1970s-80s)

- **Focus:** Pure Engineering Excellence
- **Paradigm:** Prescriptive regulation, conservative design margins.
- **Contribution:** Established foundational safety principles.

Era 2: Safety Culture (1990s-2000s)

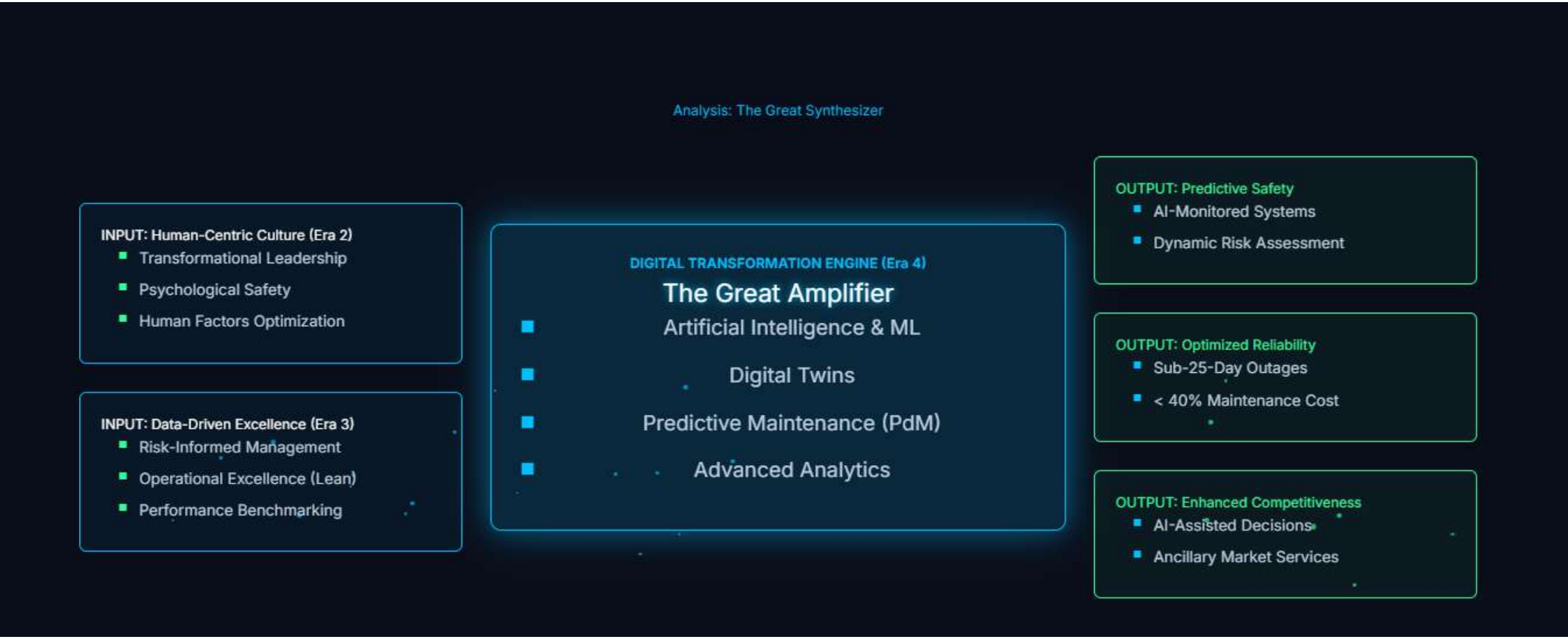
- **Driver:** Major accidents (TMI, Chernobyl).
- **Paradigm:** A shift to Human Factors & Organizational Learning.
- **Contribution:** WANO formation, global best-practice sharing.

Analysis: Learning to be "Smarter"

Era 3: Performance Excellence (2010s)

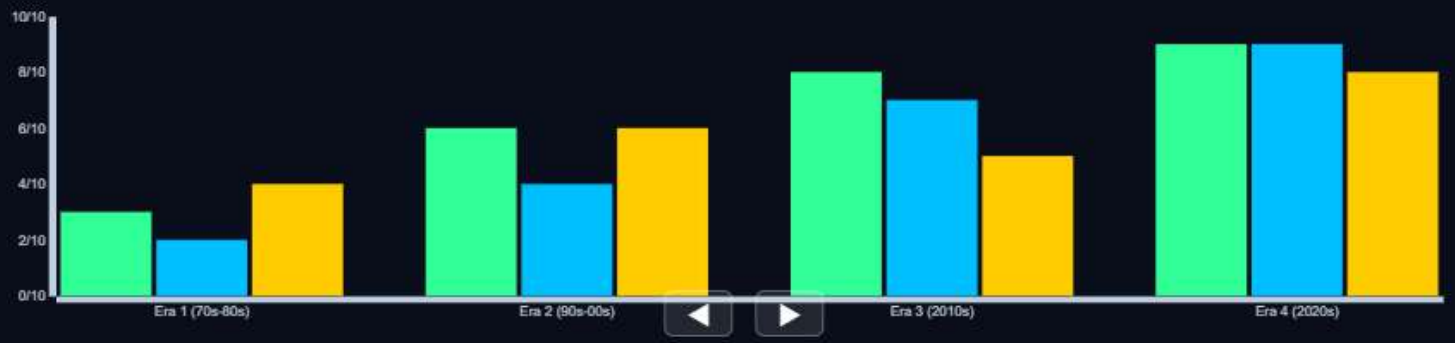
- **Focus:** Becoming safer **and** more competitive.
- **Paradigm:** Risk-Informed Decision Making (PSA) and Commercial Culture.
- **Contribution:** Operational excellence, Lean Six Sigma, optimized outages.

We had the engineering, we had the human focus. Now, we had the data-driven process.


Analysis: The Great Synthesizer
INPUT: Human-Centric Culture (Era 2)
Transformational Leadership
Psychological Safety
Human Factors Optimization
INPUT: Data-Driven Excellence (Era 3)
Risk-Informed Management
Operational Excellence (Lean)
Performance Benchmarking
DIGITAL TRANSFORMATION ENGINE (Era 4)
The Great Amplifier
Artificial Intelligence & ML
Digital Twins
Predictive Maintenance (PdM)
Advanced Analytics
OUTPUT: Predictive Safety
AI-Monitored Systems
Dynamic Risk Assessment
OUTPUT: Optimized Reliability
Sub-25-Day Outages
< 40% Maintenance Cost
OUTPUT: Enhanced Competitiveness
AI-Assisted Decisions
Ancillary Market Services

Hover over bars for details.

	1970s-1980s	1990s-2000s	2010s	2020s-2025+
Control Systems	Analog Control Systems	Digital Control Integration	Advanced Process Control	**AI-Driven Autonomous Control**
Safety Systems	Passive Safety Barriers	Defense-in-Depth Strategy	Risk-Informed Safety Systems	**Smart Safety with AI Monitoring**
Maintenance Approach	Time-Based Maintenance	Condition-Based Maintenance	Reliability-Centered Maintenance	**AI Predictive Maintenance**
Performance Monitoring	Basic Operational Metrics	WANO Performance Indicators	Advanced Analytics & Benchmarking	**Real-Time AI Analytics**
Decision Making	Engineering Judgment	Human Factors Integration	Risk-Informed Decisions	**AI-Assisted Decision Support**
Training & Competency	Basic Technical Training	Simulator-Based Training	Competency-Based Programs	**VR/AR Immersive Training**
Quality Management	QA/QC Programs	ISO 9001 Implementation	Operational Excellence (Lean/Six Sigma)	**Digital Quality Systems (ISO 19443)**
Cybersecurity	Physical Security Only	Basic IT Security	Cyber-Physical Security	**Advanced Cyber Defense & AI**



The Integrated Framework for the Digital Era

Pillar 1:
Digital Technology Integration

Pillar 2:
Transformational, Human-Centric Culture

Pillar 3:
Data-Driven Operational Excellence

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The **"engine"** of modern performance.

Predictive Maintenance (PdM)

- AI-driven analysis predicts failures before they occur.
- **Impact:** Reduces unplanned outages and cuts maintenance costs by up to **40%**.

Digital Twins

- High-fidelity virtual replicas of the entire plant.
- **Impact:** Real-time optimization, scenario analysis, and immersive training with **zero risk**.

The Integrated Framework for the Digital Era

Pillar 1:
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Pillar 2:
Transformational, Human-Centric Culture

Pillar 3:
Data-Driven Operational Excellence

Technology alone is insufficient. It requires a culture to **wield it wisely.**

Transformational Leadership

- Champions digital literacy and psychological safety.
- Empowers employees to report concerns and innovate.

Human Factors Optimization

- Ensures advanced systems are designed to minimize human error.
- Develops the workforce for a digitally-integrated plant.

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Pillar 3:
Data-Driven Operational Excellence

Using new data streams to **perfect the lessons** of Era 3.

Dynamic Risk-Informed Management

- Uses real-time data to allocate resources to areas of highest safety and operational significance.

Optimized Outage Planning

- Advanced analytics to manage critical paths and resources.
- **Result:** Top-performing plants achieve outage durations **below 25 days.**

The Unforgettable Takeaway

The data is unequivocal. The strategies with the **highest, broadest impact** are:

- **1. 1. Digital Technology**
- **2. 2. Leadership**
- **3. 3. Safety Culture**

Click to Reveal Key Strategies

> Success is the synergistic combination of **Technology, People, and Process.**

Mgmt Strategy	Safety Perf	Plant Avail	Cost Effic	Reg Standing	Workforce Eff	Innovation
Digital Tech	5	5	5	4	5	5
Leadership	5	4	4	5	5	5
Safety Culture	5	4	3	5	4	3
Predictive Mnt	4	5	5	3	4	4
Human Factors	5	4	3	4	5	3
Regulatory	4	3	2	5	2	1
Operational Ex	4	5	5	3	4	4
Risk Mgmt	5	4	4	4	3	3

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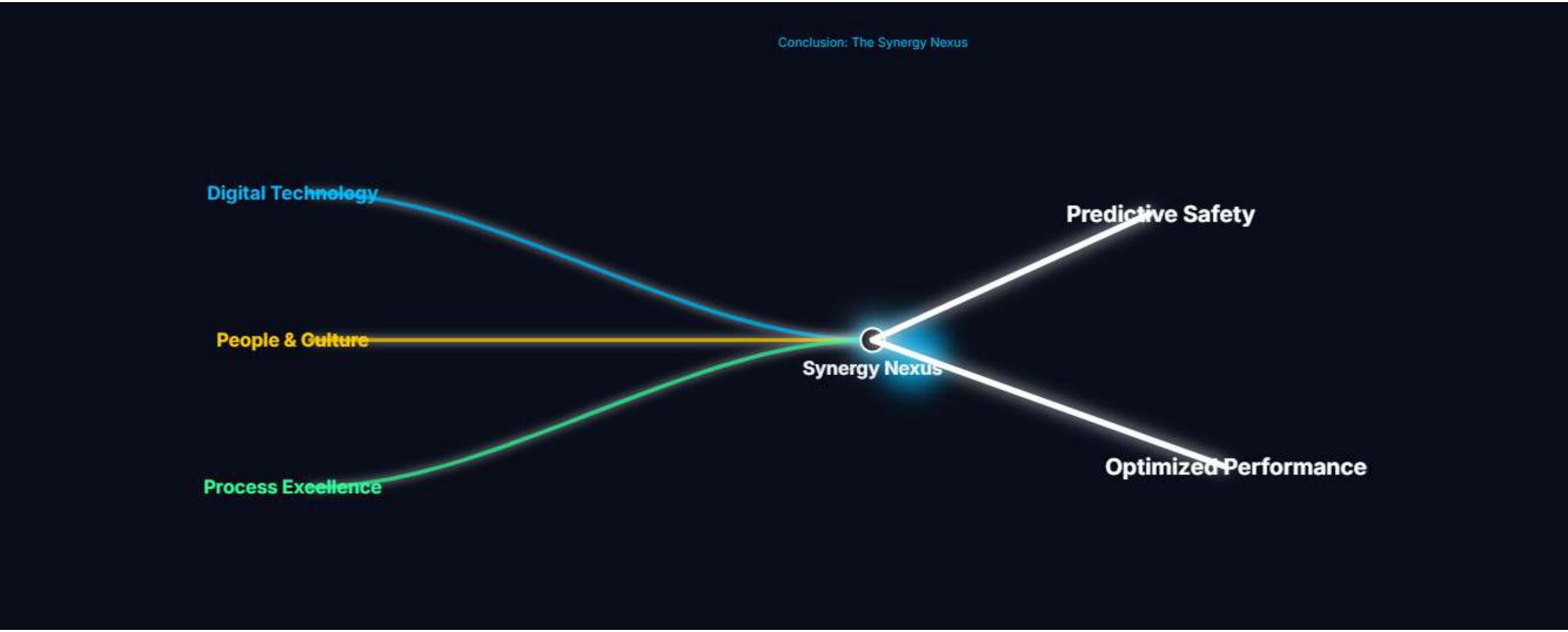
Conclusion: The Synergy Nexus
Digital Technology
People & Culture
Process Excellence
Synergy Nexus
Predictive Safety
Optimized Performance

Thank You

Questions?

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