In collaboration
with Accenture

WORLD ECONOMIC FORUM

Industries in the Intelligent Age

Intelligent Industrial Operations Outlook 2026

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Foreword

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Industrial operations are crossing a historic threshold, one where intelligence becomes the organizing principle of how the world designs, makes and moves. For decades, progress was defined by automation, integration and scale. Today, a new paradigm is emerging where operational systems perceive context, anticipate change and coordinate semi-autonomously across factories, enterprises and global value networks.

This outlook report has been developed by the World Economic Forum in collaboration with Accenture and is part of the Forum's *Industries in the Intelligent Age White Paper Series*. Informed by multiple dialogues across industry, technology and academia, it reflects a shared perspective on how this shift is reshaping the industrial landscape.

What distinguishes this moment is the convergence of frontier technologies into a new operational fabric. Advanced analytics, artificial intelligence (AI), digital twins and cyber-physical systems are no longer deployed in isolation; together, they enable environments that learn from every interaction, reconfigure in the face of disruption and continuously evolve through execution.

Intelligence has moved beyond being an overlay to becoming an integral part of operational systems, enabling organizations to respond faster to change and make better decisions across the value chain. This transformation is not purely technical; it raises new questions around trust, security and sustainability. As autonomy expands, leaders must determine how intelligence scales up responsibly and how they should strengthen governance, reshape operating models and prepare the workforce to collaborate with systems that increasingly act, reason and coordinate alongside them.

We hope this report will help industrial leaders to navigate the shift towards intelligent, adaptive operations, as well as to frame strategic choices, set investment priorities and build capabilities. The opportunity ahead is profound: to build industrial systems that are not only more adaptive but fundamentally more capable than in any previous generation.

Executive summary

Industrial operations are entering a decisive decade shaped by structural shocks and accelerating frontier technologies. Geopolitical shifts, climate volatility, workforce shortages and heightened cyber risk are disrupting traditional operating models, while advances in AI, automation, simulation, robotics and hyperconnected infrastructure are redefining what industrial systems can achieve. These forces are accelerating the shift towards intelligent industrial operations that learn continuously, adapt autonomously and operate in sync across factories, enterprises and multi-tier networks.

This report examines how these shifts play out across the value chain. It outlines the shared design logic emerging across diverse functions, as capabilities progress from early experimentation and assisted intelligence, through scaled-up human-machine collaboration, towards increasingly autonomous, self-orchestrating systems.

It introduces a future-ready transformation model (see Figure 4) that helps leaders understand how functions will evolve over the next decade, and assesses the role of different technologies in driving this evolution and their points of greatest operational impact (see Figure 5).

To deliver on this shift, leaders must focus on a small set of enablers:

- Strengthen governance for AI-driven decisions.
- Embed cybersecurity from the outset.
- Enable the workforce to collaborate effectively with intelligent systems.

As autonomy scales up across operations and ecosystems, leaders must ensure these systems create value responsibly and in line with strategic priorities.

FIGURE 1 **Executive highlights**

13

Future-ready operational functions

Function-by-function blueprint of how intelligence is being embedded across the industrial value chain, including real-world case studies.

35+

Cross-cutting transformation themes

Shifts that explain how intelligence transforms performance and how each function evolves over time.

Transformation model + Technology impact profile

Common evolution patterns and technology impact over time that guide the shift towards intelligent, interconnected and value-driven operations.

Leadership roadmap

Clear priorities to help leaders steer, sequence and scale-up intelligent transformation.

Introduction

In a fulfilment centre outside London, hundreds of robots glide across a grid delivering crates to AI-driven arms. When a gripper misjudges a soft item like a peach, the system pauses, adjusts its grip using cognitive learning from thousands of prior picks and continues without delay. Orders keep flowing and the network grows smarter every hour.[1] This is not science fiction but today's reality, pointing at a broader shift happening this very moment.

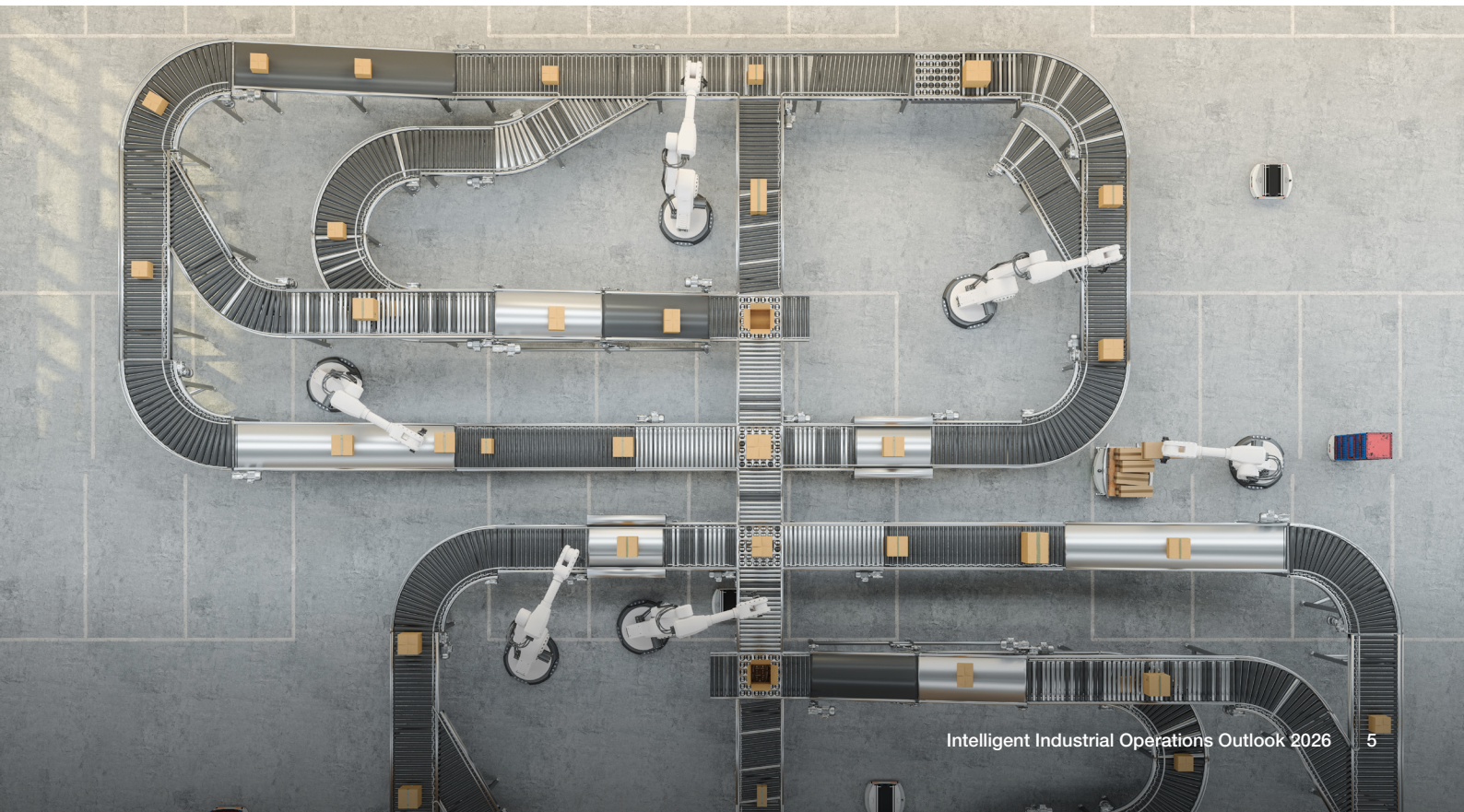
A new era of industrial intelligence is beginning to reshape how the world designs, makes and moves goods. Advances in AI, automation, connectivity, simulation and accelerated computing are elevating industrial operations to new standards of precision, agility and scale. As these capabilities converge, they are redefining operational models and opening new possibilities for end-to-end value creation across industrial ecosystems.

This transformation is unfolding amid growing global uncertainty, heightening the strategic importance of building operations that can withstand shocks, adapt quickly and compete on resilience and adaptability. Increasing autonomy and real-time orchestration are pushing organizations to rethink how industrial systems are designed to perform under constant change across complex value chains. This is unlocking a set of core ambitions that extend well beyond efficiency alone, including supply chain resilience, workforce empowerment, sharper customer focus and more sustainable operations at scale.

Across these dimensions, outcomes are increasingly shaped by design choices made upfront rather than incremental optimization over time. In the case of sustainability, for example, more efficient use of energy, materials and resources can be engineered directly into operations, embedding resource efficiency as a foundational capability rather than a downstream adjustment. However, this presents a dual mandate for industry: to capture AI-driven performance improvements while ensuring the resource cost of enabling them remains justified.[2]

> **Outcomes are increasingly shaped by design choices made upfront rather than incremental optimization over time.**

At the same time, with the rise of autonomous, hyperconnected operations, digital trust emerges as a core design requirement. Connectivity that enables real-time orchestration also expands exposure to cyber risk, requiring security, integrity and transparency to be built by design. Together, these shifts suggest that the future of industrial operations will be defined not only by technological capability but by how thoughtfully organizations apply it to strengthen performance, resilience, sustainability and the role of talent.



1 Emergence of intelligent ecosystems

Compounding structural shocks are forcing industrial operations to shift from efficiency-led models to adaptive resilience.

Industrial operations are at a decisive turning point. Economic volatility, climate pressures, rapid technological advances and geopolitical fragmentation are intensifying the strain on traditional efficiency-led models of competitiveness.

In this evolving landscape, resilience, adaptability and ecosystem-level collaboration are becoming essential capabilities for navigating increasingly complex and interconnected operating environments.

1.1 Eight key forces driving strategic imperatives

In its June 2025 publication, *From Shock to Strategy: Building Value Chains for the Next 30 Years*, the World Economic Forum identified eight key forces reshaping global manufacturing and steering strategic decision-making over the next three decades. Table 1 aligns each global driving force with a corresponding strategic imperative, illustrating how industrial leaders can translate disruption into long-term advantage. Together, these strategic imperatives define a new industrial paradigm that is rooted in digital resilience, adaptive ecosystems and sustainable value creation for the decades ahead.

These forces form the broader strategic context for the transformations explored throughout this report, shaping how industrial functions evolve across the ecosystem.

TABLE 1 | **Eight key forces driving strategic imperatives**

Driving force	Strategic imperative
Global relations and trade	**Regionalized, adaptive networks** — Develop diversified, digitally enabled regional supply chains — Transition from reactive adaptation to proactive orchestration to remain competitive amid market fragmentation
Regulatory complexity	**Digital compliance** — Automate monitoring and reporting with AI and digital twins — Use scenarios and governance tools to anticipate regulatory change
Consumer behaviour and expectations	**Customer-centric agility and traceability** — Use real-time insights for agile production and rapid response — Embed transparency and traceability to build trust
Climate disruption	**Resilient and circular operations** — Strengthen resilience with real-time analytics — Adopt circular resource strategies to reduce exposure and impact

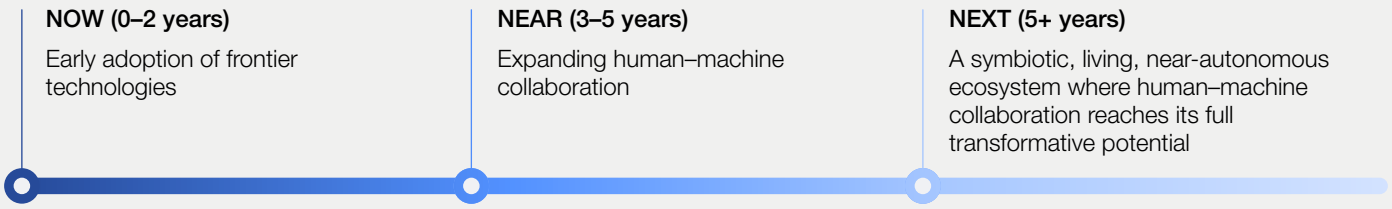
Driving force	Strategic imperative
Technology evolution	**Accelerated digital transformation** — Scale up AI, robotics, quantum, IoT and cloud across operations — Use interoperable systems and digital skills for agility and innovation
Cybersecurity	**Intelligent security integration** — Embed cybersecurity across operational layers — Use AI-driven detection and automated response for proactive protection
Workforce and skills	**Human-machine collaboration** — Accelerate digital reskilling and deploy automation to fill gaps — Combine robotics, AI knowledge systems and flexible models for synergy
Social equity	**Operational inclusion and workforce empowerment** — Embed inclusive practices across operations — Expand digital access, fairness and empowerment for underrepresented groups

1.2 Intelligent ecosystems will define the next era

Transformation timeline: NOW–NEAR–NEXT

This report outlines a forward-looking perspective on the evolution of industrial operations over the next decade and the shifts reshaping how value is created end-to-end. Rather than prescribing a single pathway, it frames progress through three "NOW–NEAR–NEXT" horizons (see Figure 2) that help organizations to understand emerging capabilities, anticipate shifts across the value chain and assess how today's choices may shape tomorrow's operating models.

FIGURE 2 **Transformation timeline**



The report incorporates insights from interviews with industry leaders across diverse sectors and leading global companies, along with publicly available information and secondary research. It evaluates manufacturing capabilities based on observed best practices and global case studies.

Three layers and 13 functions of industrial operations

Industrial operations can be understood through three interconnected layers that span physical production to global coordination:

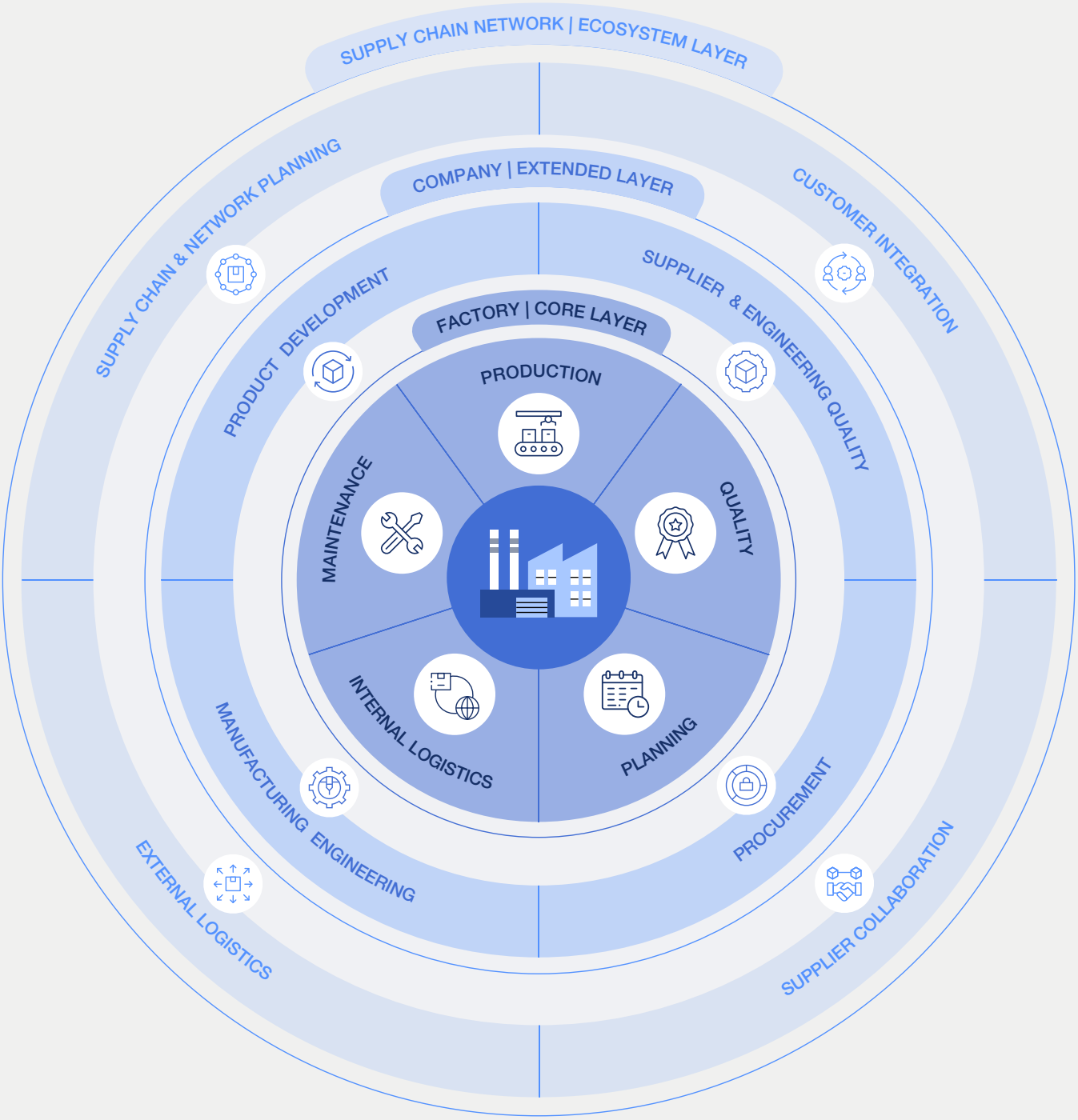
- **Factory | Core layer**: production-adjacent activities where physical assets, digital systems and human oversight integrate to convert materials into finished products.
- **Company | Extended layer**: enterprise-level capabilities that direct, coordinate and continuously refine how manufacturing operates.
- **Supply chain network | Ecosystem layer**: broader network that synchronizes flows across all stakeholders to coordinate and respond in real time.

Collectively, these three interconnected layers frame how operational functions contribute to value creation, emphasizing that operational performance is now driven across the enterprise and broader ecosystem. Figure 3 illustrates this interconnected view, showing operations as integrated networks rather than isolated functions.

The 13 future-ready operational functions considered in this report are as follows:

1. Planning
2. Production
3. Quality
4. Maintenance
5. Internal logistics
6. Procurement
7. Manufacturing engineering
8. Product development
9. Supplier & engineering quality
10. Supply chain & network planning
11. External logistics
12. Customer integration
13. Supplier collaboration

FIGURE 3 **Three interconnected layers integrate 13 operational functions**

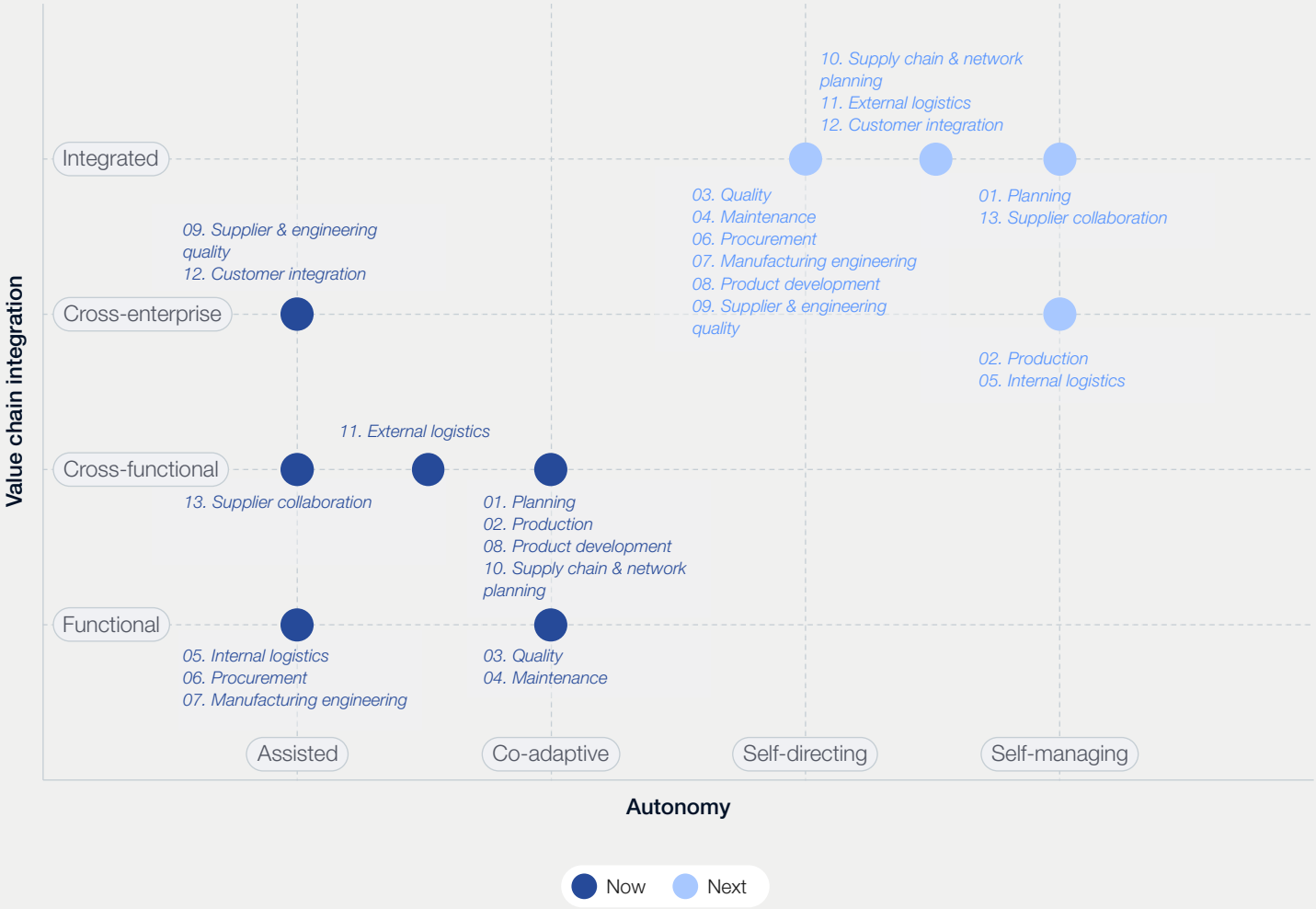


How operational functions evolve matters as much as how far they progress. When efficiency or automation are pursued in isolation, progress plateaus. In contrast, functions that build autonomy while also deepening ecosystem integration are better able to scale up and sustain impact.

The **transformation model** presented in Figure 4 captures the shared pathways through which these 13 operational functions evolve, even as each follows its own distinct trajectory. The figure offers a consolidated view that illustrates how durable transformation depends on advancing across the two dimensions of autonomy and integration together.

FIGURE 4 **Transformation model**

Transformation of operational functions towards fully integrated, self-managing operations



Interpretation of the graph

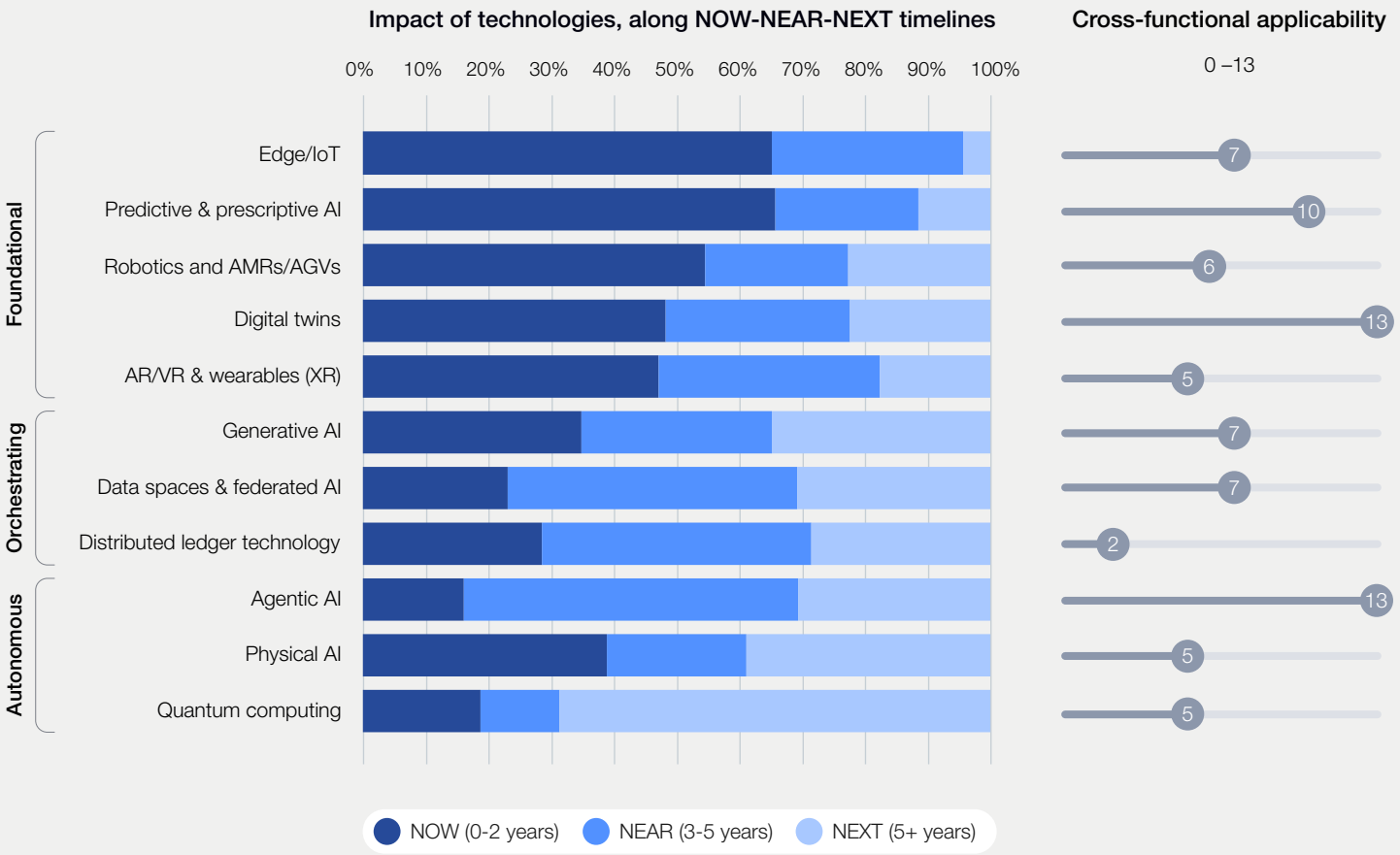
1. **Autonomy (x-axis)**: shows how an operational function can operate intelligently and independently, progressing from human-led decision-making ("assisted") to human-AI collaboration ("co-adaptive"), then AI-orchestrated ("self-directing") and finally to self-managing systems.
2. **Value chain integration (y-axis)**: indicates how widely an operational function integrates across the value chain, from functional silos, across functions and enterprises, to multi-enterprise collaboration.

The functional progression described above does not occur independently of technology choices. Movement from assisted to self-managing and from siloed to integrated ecosystems depends on how enabling technologies are introduced and sequenced. The technology impact profile that follows translates this progression into a capability view, showing how key technologies shape the timing and breadth of enterprise transformation.

The chart in Figure 5 visualizes the assessed business impact of key technologies on industrial operations across time horizons based on function level assessments, informed by this study's themes and evolution narratives:

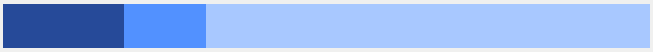
- Each technology was assessed across 13 operational functions and time horizons (NOW–NEAR–NEXT) using a consistent 1-5 impact scale ranging from early pilots to transformational change.
- The chart normalizes results to highlight when impact is expected to scale up.
- This chart does not represent a general market view of technology.

FIGURE 5 **Technology impact profile**



Interpretation of the graph

1. **Coloured bars**: These indicate the share of expected impact by horizon: NOW (0-2 years), NEAR (3-5 years), NEXT (5+ years). A larger segment means more of the technology's impact is expected to materialize in that horizon.



2. **Technology blocks (foundational, orchestrating, autonomous)**: The order of these blocks indicates the ramp-up of capability and readiness grouped into foundational, orchestrating and autonomous technologies; it highlights how foundational technologies enable more advanced capabilities over time and unlock longer-term impact.

3. **Cross-functional slider**: This represents the number of distinct operational functions (out of 13) for which a technology creates material relevance in at least one theme/use case for that function.

Key insights for leaders

- **Value compounds through capability layering**: Foundational capabilities enable orchestration at scale, and orchestration enables autonomy, so system-level impact comes from building an integrated capability stack rather than adopting isolated point solutions.
- **Timing of impact matters**: A technology's strategic importance depends on when it contributes along the journey, not only on its immediate or local benefits.
- **Sequencing outweighs selection**: The success of transformation depends less on choosing individual "breakthrough" technologies and more on building capabilities in the right order so that intelligence can scale up reliably and sustainably.
- **Impact scales through breadth of operations transformed**: Impact grows as technologies progress from optimizing single functions to transforming multiple, end to end operations across the enterprise.

Reading guide for the following chapters

The next three chapters examine the evolution of the 13 operational functions introduced in Figures 3 and 4 across the NOW–NEAR–NEXT horizon through a set of 35+ cross-cutting transformation themes. Each theme represents a transformation pathway within a function, illustrating how operational approaches evolve over time in response to increasing complexity, scale and shifting performance expectations.

These transformation pathways are examined at Factory level in Chapter 2, Company level in Chapter 3 and Supply chain level in Chapter 4.

To illustrate the potential impact of each theme, key performance indicators (KPIs) are included to indicate how performance may improve as capabilities evolve.

BOX 1

KPI impact legend

For each theme, key metrics and their expected progression over time are outlined as follows:

↑ Indicates increase in the KPI value

↓ Indicates decrease in the KPI value

Represents magnitude of improvement, regardless of direction – larger Harvey balls indicate greater impact, whether from increasing a metric (e.g. throughput) or reducing it (e.g. downtime). This assessment is qualitative and directional, not a precise or scientific measurement.

2 Factory | Core

Industrial intelligence is reshaping factory operations, enabling real-time coordination of machines, people and materials.

Driven by advances in AI, automation and connectivity, factories are entering a new era of intelligent, self-optimizing systems. Over the next decade, operations will shift from linear discrete functions to orchestrated ecosystems where machines, digital systems and people collaborate continuously in real time.

Decisions will increasingly be made at the edge: algorithms anticipating disruptions, reconfiguring workflows and synchronizing material, labour and energy across the entire network. They will optimize not just individual sites but collective performance, while reducing high-effort, repetitive work on the frontline.

Human roles will evolve towards supervising autonomous processes, validating insights and steering exceptions. The result is a new operational paradigm: adaptive, resilient and sustainable factories that continuously improve and serve as the intelligence hubs of wider production networks.

2.1 Planning

Constrained by volatility of demand, inflexible planning cycles and fragmented visibility, today's planning approaches struggle to keep pace with rapid change, leaving factories slow to respond. The future is **intelligent and resilient planning** – an evolution towards AI and simulation-first adaptive systems that learn continuously, anticipate disruptions and synchronize decisions across the value chain.

PLANNING

THEME 1 Autonomous and federated multi-agent planning

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
AI agents enable self-healing operations by rebalancing operational signals (e.g. production, assets, workforce, energy and demand) within factories, while a federated network of factories securely co-plans in real time, absorbing shocks and adapting to changing demand.[3]	**Simulation-driven, reactive** — Simulation-based planning provides cross-functional visibility. — Operational signals are used to adjust schedules and resources during disruptions, with actions remaining largely human-led. — Federated planning pilots connect OEMs with Tier-1 and Tier-2 suppliers through shared digital twins, enabling secure data sharing across supplier and customer networks for capacity, material and constraint visibility.	**Agent-first, adaptive** — Multiagent AI enables planning to shift from "plan and execute" to "sense and adapt", incorporating physics-based constraints to improve simulations' realism. — Collaborative multi-agent AI links machines, lines, workers and partner sites through digital twins and physics-grounded models to coordinate operational signals in real time. — AI agents and planners collaboratively adjust production slots, routes and schedules in near real time, learning from disruptions across connected sites.	**Living, autonomous networks** — Autonomous, self-healing planning networks operate across multi-plant and multi-enterprise ecosystems. — Physical AI continuously blends real world feedback (e.g. machine vibrations, material behaviour, energy usage, workforce ergonomics) with accelerated simulation to train autonomous decision agents (e.g. MEGA Blueprint).[4] This enables planning networks that self-heal, rebalance flows and optimize under real constraints, not just digital ones. — These networks continuously synchronize with ecosystem-wide demand and supply shifts.
Schedule adherence ↑			
On time in full ↑			

Carbon-intelligent planning

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Planning evolves to balance lead time, cost, emissions and circularity, embedding energy and carbon optimization into networks by design.	**Carbon visibility and accounting** — AI models predict process-level energy use and CO_2 intensity. — Carbon KPIs are piloted on select production lines using IoT and edge data to identify optimization opportunities.	**Carbon optimization** — Prescriptive AI optimizes plant-level operations for cost-carbon trade-offs. — Systems dynamically schedule production around availability of renewables and local energy prices, shifting energy-intensive tasks into low-carbon windows. — Optimization remains enterprise-centric, guided by business priorities and known grid conditions.	**Planet-aware systems** — Optimization expands beyond the enterprise to the energy ecosystem. — Agentic and quantum solvers connect factories, suppliers and power networks into grid-interactive, carbon-intelligent systems. — These networks autonomously balance carbon, cost and capacity in real time.
Energy cost ↓			
Carbon footprint ↓			

PLANNING | CASE STUDY

ACG Packaging Materials

Intelligent production planning with digital twin and machine learning

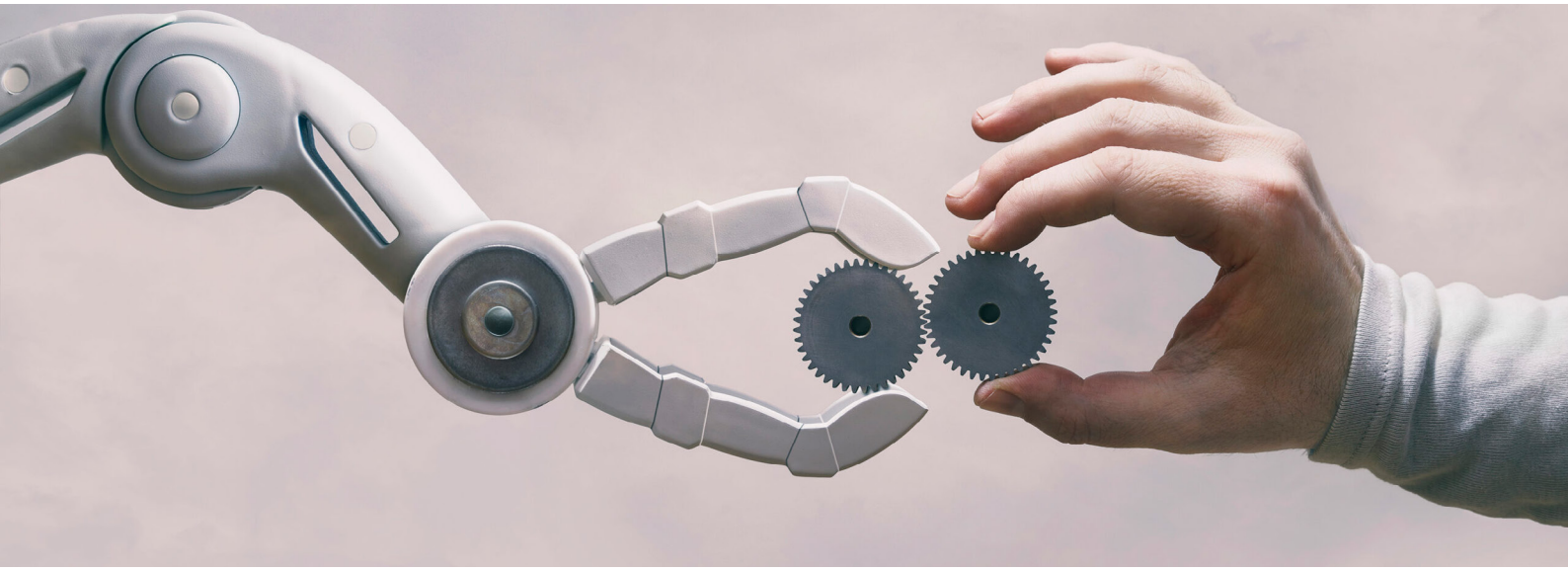
Challenge	Solution	Impact
The company's Satara site in Maharashtra, India produces over 5,000 SKUs* across 40+ product types. Production involves complex routings and frequent changeovers. Around 30% of orders are rush orders. Planning was manual and siloed, resulting in low-capacity utilization, long production lead times and poor OTDIF.*	Chronos, a digital twin-driven production planning and optimization solution, was implemented combining reinforcement learning (RL), optimization algorithms and simulation. This RL-based planning model creates a demand-driven seed plan, which is expanded into 1,000+ optimized plan variants. Each variant is simulated using a plant digital twin to evaluate KPIs such as lead time, capacity utilization and changeovers, enabling recommendation of the optimal production plan.	The transformation strengthened operational efficiency, accelerated lead times and enhanced overall delivery reliability, including: – 42% reduction in change over time. – 23% reduction in production lead time. – Increase in capacity utilization from 62% to 78%.

Note: *SKU = stock keeping unit; OTDIF = on-time delivery in full.

2.2 Production

Line-level inefficiencies, rigid execution schedules and fragmented shopfloor visibility constrain production today, causing waste, downtime and uneven performance despite automation.

Adaptive and autonomous production replaces this with self-optimizing, real-time systems that enable dynamic, self-balancing operations and resilient, sustainable performance.



PRODUCTION

THEME 1

Cognitive and carbon-aware production systems

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Enable production systems that learn continuously and adjust in real time, co-optimizing performance and resource intensity by embedding carbon and energy signals directly into cognitive decision-making.	**Responsive production control** — Edge analytics and digital twins detect real-time process drift and carbon-intensive steps. — Integrated dashboards link production KPIs with energy and emissions data, while AI copilots guide operators with targeted adjustments that stabilize output and avoid unnecessary resource use, with decisions remaining human-led.	**Adaptive lines with resource-smart optimization** — Lines autonomously recalibrate parameters, routing and energy use within defined guardrails. — Digital twin simulates flow, quality and resource intensity and automatically selects lower-carbon windows or energy-efficient setups without compromising throughput.	**Autonomous, low-impact production networks** — Production operates as a distributed, self-optimizing network across lines and plants. — AI autonomously coordinates capacity, energy, materials and pricing to meet cost, performance and net-zero goals. — Quantum and federated AI synchronize production rhythms with renewable availability and grid signals, creating resilient, low-impact ecosystems that continuously optimize for performance and minimal emissions with minimal central control.
First pass yield ↑			
CO_2 emissions intensity ↓			

PRODUCTION

THEME 2 Augmented workforce enablement

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Amplify human potential with AI and immersive systems that improve safety, agility and performance.	**Augmented task assistance** — Wearables, augmented reality (AR) and AI copilots for workers provide real-time safety, ergonomic monitoring and guided tasks, reducing fatigue and errors while improving situational awareness on shopfloor.	**Adaptive workforce orchestration** — Mixed-reality environments let workers rehearse complex, high-risk operations offline to uncover issues before they hit production. — Adaptive workflows deliver right-time instructions and micro-training thereby reducing cognitive load and error rates.	**Cognitive human-machine teaming** — Cognitive exoskeletons, autonomous assistants and industrial metaverse systems work alongside humans, taking over routine decisions and physical strain. — Workers shift to high-value judgement and exception leadership as autonomous systems execute tasks safely across global networks.
Error rate ↓			
Injury rate ↓			

PRODUCTION

THEME 3 Autonomous physical operations

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Transform production from fixed automation to physical AI-driven, autonomous robotic execution at scale.	**Assisted robotic operations** — Robotics automate repetitive, precision-driven and ergonomically heavy tasks at individual stations. — AI-enhanced perception improves accuracy in assembly, inspection and material handling. — Robots learn from demonstrations, reducing manual programming and set up.	**Coordinated robotic systems** — Autonomous mobile robots manage material flows using real-time production and inventory signals. — Multi-robot systems coordinate tasks across work cells, based on product mix and schedule changes. — Physical AI enhances adaptive motion planning and quality sensing, without intervention.	**Self-configuring autonomous cells** — General-intelligence robots autonomously reason and adapt in real time to optimize execution across changing products and conditions. — Robots, material movement systems and equipment operate as integrated autonomous units connected to planning networks, enabling unattended execution.
Overall equipment effectiveness (OEE) ↑			
Labour productivity ↑			

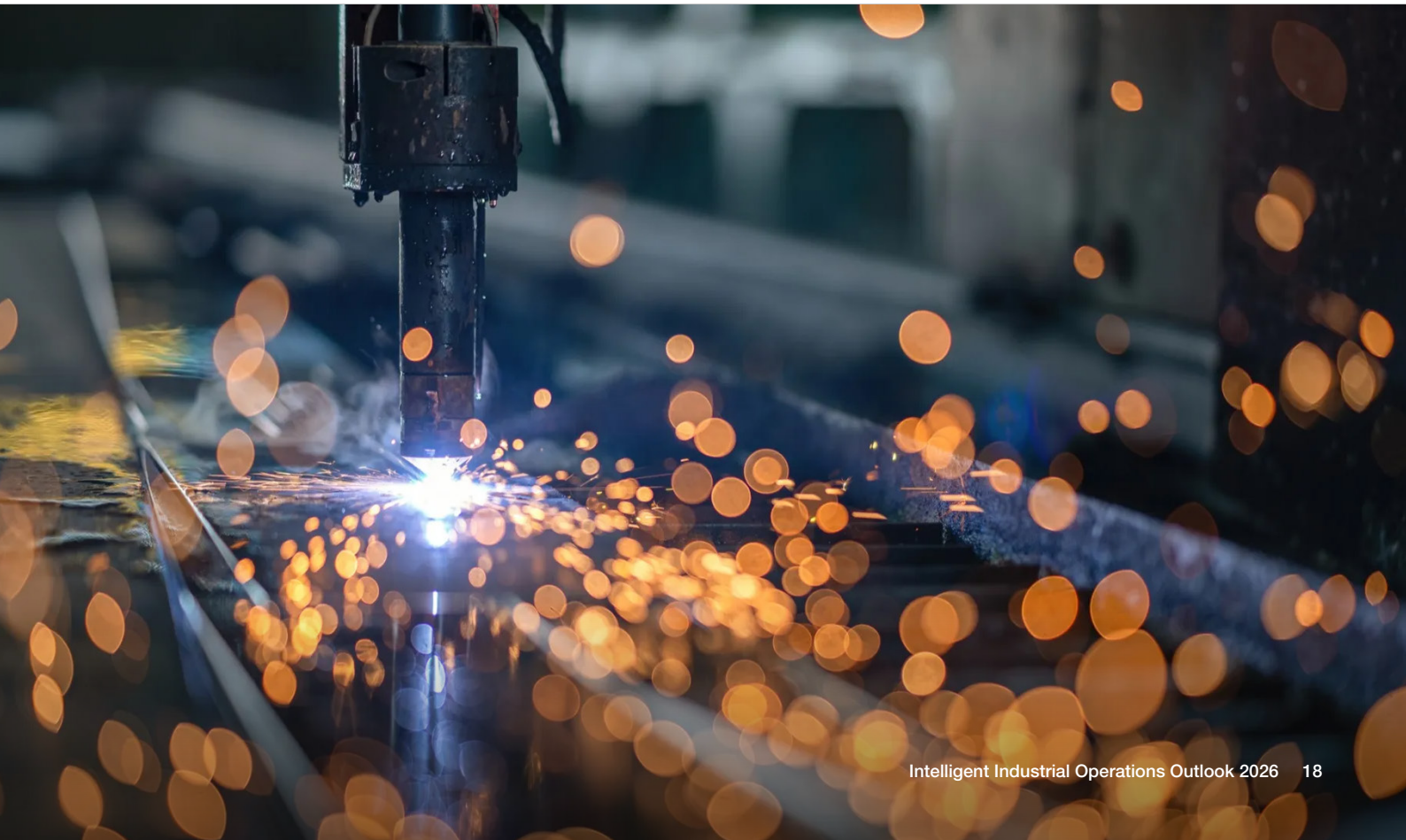
PRODUCTION | CASE STUDY

Saudi Aramco

Smart well completion and mission-driven artificial lift intelligent systems

Challenge	Solution	Impact
Khurais Producing Oil Field, operated by Saudi Aramco, is a large-scale onshore asset with complex production operations. The scale of assets and wells required improved production efficiency, reduced equipment downtime and enhanced asset reliability to support sustainable, high-volume operations.	A smart well completion and mission-driven artificial lift solution was implemented using industrial IoT, advanced analytics and machine learning. More than 95,000 connected devices enabled real-time monitoring, predictive maintenance and automated control of downhole and surface assets. Advanced analytics supported remote operations, proactive decision-making and continuous optimization of production performance across the field.	The solution transformed production operations by improving efficiency, reliability and decision-making at scale, delivering measurable gains in output and asset performance, including: – 15% increase in oil production – 5% reduction in production losses – 80% improvement in equipment reliability.

> **Khurais oilfield's digital transformation is indicative of how Aramco is successfully harnessing disruptive technology to reinvent upstream operations; rendering our business future-fit and our production activities smarter, safer, more cost-effective and more sustainable.**
>
> Mohammad Al Mulhim, Senior Vice President Southern Area Oil Producing, Aramco



2.3 Quality

Quality today remains reactive, operating as a downstream checkpoint with limited visibility and control. Manual inspections, inconsistent data and delayed feedback limit early defect detection as product complexity, connectivity and sustainability demands grow. The future is **intelligent quality orchestration**, enabling real-time prediction, prevention and self-correction, making it the backbone of zero-defect manufacturing across smart factory ecosystems.

QUALITY

THEME 1

Self-evolving quality intelligence

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Build a self-learning quality ecosystem where digital twins and agentic AI pre-emptively detect, prevent and adapt to variations in real time, ensuring zero-defect performance.	**From detection to prediction** — AI models analyse sensors and process data to detect and flag anomalies before they occur. — IoT vision, poka-yoke (mistake-proofing) tools and robotic inspection systems capture defects consistently and guide operators with real-time alerts and corrective insights.	**Autonomous quality guardians** — Digital twins simulate material and process behaviour to predict performance and prevent defects. — AI agents act as "quality guardians", fine-tuning parameters in real time and enabling closed-loop optimization across lines, shifts and machines.[5] — Autonomous inspection robots and mobile "cobots" perform adaptive visual and dimensional checks.	**Cognitive quality ecosystems** — Federated, agentic AI networks unite design, production and suppliers into an intelligent quality ecosystem. — Quantum-enhanced twins anticipate multi-variable deviations and orchestrate self-healing, zero-defect operations across plants. — Robotic inspection and sensing systems feed trusted, real-time data and client feedback into shared quality graphs, strengthening transparency and enabling end-to-end assurance.
Right-first-time quality ↑			
Cost of poor quality ↓			

QUALITY

THEME 2 Digital quality provenance

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Create a trusted digital backbone for quality that provides verifiable, real-time traceability of materials, processes and compliance across the value chain.	**From records to digital proof** — Blockchain and IoT pilots record material origin, production batches and inspection data, supporting auditability and compliance verification.	**Intelligent product passports** — AI verifies provenance data integrity across suppliers, linking digital product passports and sustainability KPIs through secure and standardized platforms.	**Trusted, self-certifying networks** — Self-verifying digital passport of every product captures design, production and customer-use data enabling real-time compliance and certification.
Audit readiness time ↓			
Traceability coverage ↑			

QUALITY

THEME 3 Carbon-intelligent and circular quality systems

Evolutions of themes

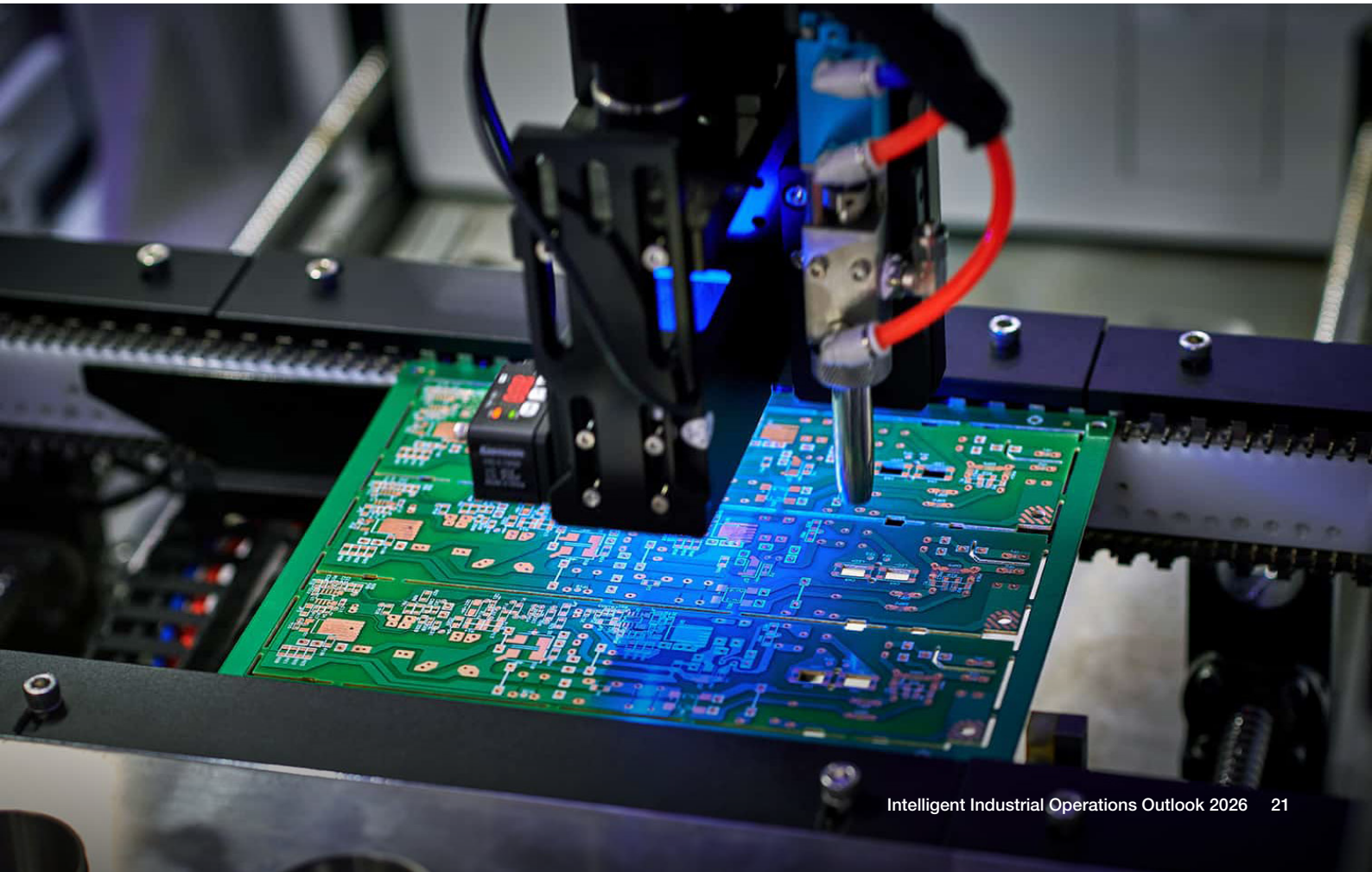
Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Embed sustainability directly into quality processes to minimize scrap and rework at the source, improve repairability and reuse, and orchestrate in-factory circular flows.	**Visibility into defect-driven material losses** — Quality begins tagging and classifying defect outcomes ("repairable, refurbishable, recyclable"), adding basic circularity indicators into dashboards. — Early waste-mapping connects scrap and rework directly to defect causes, establishing the baseline for repairability- and reuse-orientated quality control.	**Prescriptive circular optimization** — AI models optimize yield, cost and emissions using quality levers such as re-certification vs. scrap decisions, inspection-guided material routing and repair/reuse to improve circular efficiency. — Quality and sustainability teams jointly optimize closed-loop outcomes.	**Autonomous regenerative quality loops** — Agentic AI autonomously routes components for repair, refurbishment or recycling and manages re-inspection and re-certification cycles. — Quality systems continuously optimize for material lifetime extension and minimal waste. — Live quality-circularity data feeds design for durability and ease of disassembly, enabling near-zero-waste factory operations.
Material circularity rate ↑			
Carbon intensity ↓			

QUALITY | CASE STUDY

Western Digital Corporation

Operationalizing quality excellence through intelligent automation

Challenge	Solution	Impact
Western Digital Corporation sought to transform its quality function by reducing manual dependency, improving decision accuracy and enabling scalable, real-time quality operations across global manufacturing sites.	A virtual process assistant (VPA) framework was implemented to enable human-AI collaboration across manufacturing quality operations. The solution combined data capture, analytics, decision support, automated actions and feedback loops to support real-time quality management. Specialized VPA supported defect detection, quality control and process monitoring. Critically, these VPAs were designed not merely to optimize local efficiency at individual sites, but to coordinate globally and orchestrate decisions across Western Digital's manufacturing network. This multi-agent architecture enabled quality intelligence from one facility to immediately benefit others.	The solution transformed quality operations by, for example: – 30% reduction in manual quality errors. – 5× increase in workforce productivity through AI-powered digital assistants. – Establishing a scalable, human-led intelligent manufacturing operating model.



2.4 Maintenance

Maintenance today focuses on preventing failure rather than assuring sustained asset performance. Time-based servicing and manual diagnostics respond after degradation has already occurred, increasing downtime, energy waste and total cost of ownership as complexity rises. The future is **lifecycle-driven maintenance performance systems** where continuous sensing, prediction and self-optimization sustain reliability, efficiency and low-carbon operations across the asset lifecycle.

MAINTENANCE

THEME 1 **Agentic maintenance ecosystems**

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
AI agents coordinate maintenance across OEMs. Suppliers and plants create a self-optimizing network that improves uptime, reduces cost and lowers carbon footprint.	**From reactive to predictive maintenance** — IoT provides visibility into asset performance, energy consumption and component wear. — Predictive AI forecasts failures enabling condition-based maintenance. — Digital twins capture asset behaviour and lifecycle patterns, laying the foundation for intelligent orchestration.	**Collaborative, AI-orchestrated maintenance** — Focus shifts from asset level optimization to network-wide orchestration across plants and partners. — Agentic AI coordinates maintenance windows, spare parts and technician assignments across plants and suppliers through shared digital twins. — Human supervisors oversee AI recommendations as systems learn from disruptions to reduce downtime and optimize resource across sites.	**Autonomous, self-healing maintenance networks** — Federated AI agents optimize decisions across OEMs, suppliers and sites forming a self-learning, ecosystem-wide maintenance network. — They autonomously predict, prioritize and execute actions across partners reconfiguring systems before issues arise. — Human intervention shifts to governance and resilience strategy, as systems aim for zero unplanned downtime.
Unplanned downtime ↓			
Maintenance cost ↓			

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Extend asset life and build adaptive, circular systems that maximize longevity, reuse and refurbishment, ensuring operational continuity.	**Visibility into asset lifecycle** — Digital twins map asset health, energy use and material flows, providing a unified view of utilization and degradation. — These insights guide repair, refurbishment and resource allocation decisions.	**AI-driven circular optimization** — AI optimizes asset lifecycles by balancing cost, carbon and reliability. — Focus remains on maximizing value from individual assets. — Predictive analytics guide repair-vs-replace decisions and embed recovery strategies into maintenance planning.	**Self-healing, regenerative asset network** — Self-learning networks enable closed-loop asset reuse and refurbishment across plants. — Systems reallocate components and resources to sustain operations during disruptions. — Assets become active participants in resilience, co-optimizing with their digital twins to achieve regenerative, net-zero outcomes.
Asset lifespan ↑			
Maintenance cost per asset ↓			

MAINTENANCE | CASE STUDY

William Grant & Sons

From reactive maintenance to predictive operations in a 138-year-old distillery

Challenge	Solution	Impact
At their Girvan distillery, William Grant & Sons faced regular unplanned downtime because of heavy reliance on reactive maintenance – 40% of repairs were mid-emergency, rather than proactive fixes. The downtime drained resources and stifled output.	Partnering with IFS Nexus Black, the distillery put in place an AI-driven predictive maintenance solution tailored for complex operations. The system combines historical asset data with process flow logic to predict failures before they happen, assess downstream impacts and tell the team what to fix, when and how. Multimodal intelligence means engineers can diagnose problems based on audio, video or vibrations. Continuous learning from fault reports makes the operation more resilient for the future.	Once in business-as-usual mode, the distillery estimates: – Annual savings of £8.4 million at this one site because of less unplanned downtime, more first-time fix rates and a more reliable operation.

2.5 Internal logistics

Internal logistics today is constrained by forklift-centric movement, fixed routing and manual dispatching. Material flows fail to absorb production variability, leading to idle time, energy waste and congestions. Limited connectivity across systems restricts visibility and flow efficiency across the shop floor. The future is **connected and autonomous intralogistics** – where self-managing, real-time adaptive flows orchestrate materials dynamically, enabling agile, energy-efficient and circular factory networks.

INTERNAL LOGISTICS

THEME 1

AI-orchestrated intralogistics

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Enable AI-driven orchestration of internal logistics assets – such as autonomous mobile robots (AMRs), automated guided vehicles (AGVs), conveyors and cranes – creating synchronized, responsive, energy-aware material flows aligned to production demand.	**Automated but isolated logistics** — AMRs and AGVs use onboard sensors (e.g. LIDAR, vision) for local navigation. — Fleets are centrally controlled but siloed with limited awareness of plant-wide traffic or demand fluctuations. — Automation improves safety and task execution, but material flows remain fragmented and reactive.	**AI-connected, predictive logistics** — Agentic AI coordinates robots, conveyors and cranes across facilities through shared digital twins. — Demand and floor data enable predictive routing, dynamic load balancing and congestion avoidance. — Assets act as “logistics agents”, adjusting routes and priorities while operators supervise end-to-end flow.	**Self-optimizing logistics networks** — Physical AI matures from task-level autonomy to goal-driven logistics systems, where embodied robots learn, reason and coordinate at a network level. — Assets self-organize into adaptive networks, dynamically reconfiguring routes, roles and flows based on demand, energy constraints and disruptions without human orchestration.
Intralogistics lead time ↓			
Resource utilization ↑			

INTERNAL LOGISTICS

THEME 2

Human-robot collaboration

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Enable safe, adaptive intralogistics, where humans and robots collaborate seamlessly to improve productivity, ergonomics and safety.	**Safe co-working** — Cobots and mobile robots assist operators with dynamic safety zones and 3D vision. — AR tools support workers in picking, assembly and movement accuracy while minimizing collisions and manual strain.	**AI-assisted, adaptive collaboration** — AI monitors operator posture, fatigue and movement data to balance workloads between humans and robots. — Wearables and digital twins anticipate risks and reassign tasks in real time, reducing fatigue and improving safety and precision.	**Intent-driven, self-adapting workforces** — Agentic systems understand human intent through multimodal sensing (e.g. voice, gesture, biometrics). — Humans, robots and AI operate as a unified adaptive workforce, dynamically reallocating tasks based on safety and demand. — Cognitively aware environments predict needs and self-adjust ergonomics.
Safety incident rate ↓			
Workforce productivity ↑			

INTERNAL LOGISTICS

THEME 3

AI-enabled logistics traceability and material readiness

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Enable real-time material traceability and readiness across internal logistics to reduce lead times and ensure just-in-time operations across warehouse, shopfloor and production.	**Digitized tracking and visibility** — IoT sensors, RFID and barcode systems digitize material movement, enabling dashboards that display material locations, usage and line-side inventory, reducing manual checks.	**Predictive traceability and readiness** — AI and digital twins forecast shortages, delays and compliance gaps. — Automated replenishment and traceability validation enable proactive, just-in-time material readiness.	**Autonomous, self-verifying supply flows** — Federated AI and blockchain networks autonomously verify flow origin and compliance. — AI agents self-manage material synchronization and readiness across partners in real time.
Material readiness rate ↑			
Lead time ↓			

Schneider Electric

Innovating intralogistics: autonomous and collaborative robots powered by mobile robot expert

Challenge	Solution	Impact
At Schneider Electric, manual "milk run" material handling created ergonomic risks, consumed operator time and limited scalability in high volume production, driving the need for fully automated, end to end last mile material movement.	The solution integrates collaborative robots and AMRs orchestrated through Schneider Electric's EcoStruxure mobile robot expert, connected with Kanban and warehouse management systems (WMS) systems for real-time material movement data. AMRs dynamically adapt to shopfloor conditions while a Lexium Cobot – a collaborative robotic arm equipped with a servo-controlled gripper – mimics operator actions to automatically lift, transfer and place heavy boxes across multiple locations. An AI-based vision system enables precise pick and place of heavy boxes. The integrated EcoStruxure software ecosystem enables centralized control, interoperability and real-time monitoring.	The solution automated end-to-end material handling, delivering: – 100% elimination of ergonomic risks. – 15% improvement in warehouse path efficiency because of intelligent traffic coordination. – 4% increase in manpower productivity.

3 Company | Extended

Companies are becoming real-time decision enterprises where AI strengthens resilience, innovation and supplier ecosystems.

As factories become intelligent, self-optimizing systems, companies must evolve into integrated decision enterprises built on a unified digital backbone. The next decade will see a shift from function-centric execution to real-time networked operations where AI anticipates risks, optimizes specifications and strengthens supplier ecosystems, enabling enterprises to become faster, more adaptive and intrinsically resilient.

3.1 Procurement

Procurement today faces rising volatility from commodity, regulatory and geopolitical shifts, yet remains constrained by fragmented data, limited supplier visibility and manual workflows. Reactive risk management and slow decisions expose organizations as supply networks grow more complex. The future is **cognitive, autonomous procurement networks** – where AI and connected supplier ecosystems enable real-time sensing, dynamic sourcing and automated execution, transforming procurement into a strategic, intelligence-led driver of resilience and value.

PROCUREMENT

THEME 1 **Autonomous procurement execution**

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
AI-driven, touchless procurement flows where sourcing, contracting, ordering and payment execute autonomously, improving compliance, accuracy and speed across the end-to-end procure-to-pay cycle.	**Digital tasks to guided execution** — Procurement workflows are digitized across requisitioning, ordering and invoicing. — Data centralization improves visibility, but execution still relies on manual validations and exception handling.	**AI-orchestrated procurement cycles** — AI platforms unify source-to-pay data across contracts, policies, suppliers and spend. — AI identifies suppliers, validates contracts and flags compliance deviations in real time. — Exception handling becomes guided and rule-based, enabling consistent execution while humans focus on higher-value decisions.	**Agentic, touchless procurement networks** — Autonomous agents negotiate, award, execute and reconcile end-to-end procurement transactions.[6] — Contract updates, renewals, validations and exceptions are resolved automatically using real-time policies, spend insights and risk signals. — Human involvement shifts to governance as procurement becomes a self-optimizing, touchless network.
Procure-to-pay cycle time ↓			
Manual workload ↓			

PROCUREMENT

THEME 2

Data-driven and adaptive sourcing strategy

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Leverage AI and real-time market intelligence to continuously optimize sourcing decisions for cost competitiveness and strategic alignment.	**Insight-driven reviews** — Dashboards track supplier performance, market indices, spend and baseline ESG metrics to support periodic sourcing decisions. — Decisions rely on historical data and manual analysis to adjust supplier portfolios. — Strategy updates occur infrequently as the organization remains reactive to price and supply variability.	**Predictive, scenario-based sourcing optimization** — AI models forecast demand, pricing, supplier performance and sustainability risk indicators, enabling dynamic adjustments to supplier mix and contract terms. — Market signals feed into sourcing simulations that guide negotiation outcomes and category planning. — Sourcing shifts from periodic reviews to continuous optimization.	**Autonomous sourcing and strategy rebalancing** — Self-adjusting sourcing engines autonomously evaluate performance, risks and priorities. — Supplier allocation, contract updates and negotiation parameters adjust in real time. — Agentic AI rebalances supplier portfolios to maximize resilience, savings and ESG outcomes.
Sourcing cycle time ↓			
Sourcing cost ↓			

PROCUREMENT

THEME 3

N-tier supplier network visibility and risk management

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Achieve deep, multi-tier supplier visibility and proactive risk sensing through shared data platforms, digital twins and predictive analytics.	**Tier-1 monitoring and risk tracking** — Organizations track performance and risk at Tier-1 levels through dashboards and periodic audits. — Supplier issues are detected late and disruptions are managed reactively. — Multi-tier visibility is minimal, with data scattered across systems and largely dependent on manual updates.	**Predictive, multi-tier risk sensing** — Shared platforms and blockchain-based data exchanges extend visibility into Tier-2 and Tier-3 suppliers. — AI flags early risk signals from delivery, financial and compliance data. — Scenario simulations forecast disruptions, enabling proactive mitigation across interconnected supplier layers.	**Autonomous continuity networks** — A full supplier network digital twin simulates disruptions continuously, triggering automated mitigation actions such as rerouting, reallocation and alternative sourcing. — Multi-tier supply continuity becomes self-managed, with predictive engines negotiating trade-offs dynamically across the ecosystem.
Time to detect risk ↓			
Time to recover ↓			

PROCUREMENT

THEME 4

Predictive cost modelling and commodity risk intelligence

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Predictive modelling and autonomous risk engines to anticipate cost volatility and protect margins.	**Tracking to early forecasting** — Organizations track commodity indices and cost exposures via dashboards, adjusting budgets and sourcing manually. — Hedging strategies rely on periodic reviews, limiting responsiveness to volatility. — Cost actions remain reactive to market outcomes.	**Predictive cost intelligence** — AI forecasts commodity trends, cost scenarios and risk exposure in near real time. — Predictive alerts guide negotiations and budget planning. — Teams shift from retrospective analysis to proactive cost shaping.	**Autonomous margin protection engines** — AI autonomously executes hedging, rebalancing and contract adjustments using live market and supplier data. — Risk exposure thresholds are continuously optimized to protect margins. Procurement and finance jointly govern an integrated cost ecosystem.
Cost forecast accuracy ↑			
Margin at risk ↓			

PROCUREMENT

THEME 5

Circular and carbon-transparent networks

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Establish multi-tier visibility and carbon intelligence to drive scope 3 reduction, circular material reuse and cost-efficient supply ecosystems.	**Fragmented sustainability data** — Suppliers share emissions and material data using manual reports. — Distributed ledgers provide partial chain-of-custody insight, but sustainability information remains inconsistent and not actionable across tiers.	**Federated carbon and circularity intelligence** — Shared networks integrate supplier emissions, recycled content and waste metrics. — AI evaluates sourcing options using carbon intensity and circularity KPIs. — Teams apply these insights to supplier selection, materials and design-for-reuse strategies.	**Autonomous circular supply ecosystems** — Self-managing supplier networks dynamically balance material reuse, low-carbon alternatives and circular flows using real-time energy price and grid carbon-intensity signals. — Agentic procurement systems enable energy-aware sourcing, recycling and closed-loop supply operations.
Carbon adjusted cost per unit ↓			
Circular sourcing share ↑			

PROCUREMENT | CASE STUDY

Agilent Technologies

Strategic cost management with AI-powered procurement simulation

Challenge	Solution	Impact
Agilent Technologies, a global leader in life sciences, diagnostics and applied chemical analysis, faced procurement inefficiencies from volatile supplier pricing, limited negotiation insights and manual processes, constraining cost optimization and proactive decision-making.	Agilent implemented an AI-powered procurement intelligence solution combining machine learning, supply-market sentiment analysis and predictive analytics. The platform simulates negotiation scenarios, forecasts price movements and automates cost tracking. Advanced dashboards provide end-to-end visibility, enabling data-driven negotiations, proactive supplier engagement and faster response to market fluctuations.	The solution strengthened procurement decision-making by embedding AI-driven negotiation intelligence, improving cost control, speed and resilience in volatile markets, delivering: – 83% supplier should-cost* target achievement (up from 49%). – 90% reduction in negotiation preparation time. – $10 million+ cumulative savings over two years.

Note: *Should-cost is a data-driven estimate of a product's fair cost, based on underlying cost drivers rather than the supplier's quoted price.

> **In today's volatile supply chain, speed to decision and execution are critical. By embedding AI-driven intelligence across procurement and manufacturing, we enable accurate, fact-based decisions at scale driving cost discipline, resilience and faster responses to market dynamics for customers.**
>
> Chow Woai Sheng, Vice President, Manufacturing, Global Operations, Agilent Technologies

3.2 Manufacturing engineering

Manufacturing engineering today is anchored in static design, disconnected tools and one-time commissioning, leading to slow change cycles and growing gaps between design intent and shop-floor reality. The future is **cognitive manufacturing engineering** – where factories actively learn and improve from real-time data and co-create across ecosystems, turning engineering into a continuous, adaptive lifecycle that accelerates innovation, resilience and sustainability at scale.

MANUFACTURING ENGINEERING

THEME 1

AI-driven reconfigurable factory engineering

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Enable AI-driven self-learning factory environments where digital twins continuously optimize layouts, performance and reconfiguration.	**Digital simulation and validation** — Factories are virtually modelled in 3D, simulating material flow, robotics and ergonomics before commissioning. — AI-assisted simulations validate layouts and control logic, reducing setup time and physical trials.	**Cognitive optimization** — Integrated factory twins connect design, automation and production data. — AI models simulate throughput, energy and quality to proactively recommend reconfigurations, improving flexibility and productivity.	**Autonomous reconfiguration systems** — Cognitive factories evolve into adaptive systems. — Learning twins autonomously recommend layouts, workflows and control-logic changes to respond to product mix and demand shifts, enabling self-optimizing factory ecosystems.
Engineering lead time ↓			
Asset productivity ↑			

MANUFACTURING ENGINEERING

THEME 2

AR/VR-enabled human-machine integration

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Foster seamless human-machine collaboration using immersive and adaptive technologies to improve safety, accelerate skill development and reduce commissioning time.	**Assisted simulation and training** — AR/VR supports operator training, assembly guidance and process validation. — Virtual commissioning enables early testing of automation logic, improving setup speed and safety. — Workers gain situational awareness and ergonomic support, reducing risk during commissioning.	**Connected immersive collaboration** — Immersive environments link physical and virtual commissioning. — Remote experts collaborate through AR for live support. — Human-robot workflows simulated before go-live. — AR environments connect to live machine and line data, enabling real-time co-commissioning.	**Symbiotic interaction** — AI-driven AR interprets operator intent and coordinates real-time collaboration between humans and robots. — Interfaces adapt to optimize safety, ergonomics and task precision.
Operator safety incidents ↓			
Commissioning time ↓			

MANUFACTURING ENGINEERING

THEME 3

Closed-loop design-to-manufacturing integration

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Integrate sustainability intelligence across design and production to drive circularity, minimize emissions and enable regenerative manufacturing systems.	**Designing with visibility** — Sustainability KPIs integrated in process design. — Energy, carbon and material usage tracked through production dashboards. — Design-to-manufacturing feedback loops start to close, enabling real-time visibility into environmental performance.	**Designing for optimization** — Product and process twins exchange real-time sustainability data. — AI optimizes design and production to minimize waste, emissions and resource intensity across the value chain. — Circular design principles integrated into production planning and supply partnerships.	**Regenerative manufacturing loops** — Autonomous optimization loops dynamically minimize environmental impact. — Circular production systems self-balance material, carbon and energy flows, enabling regenerative and net-positive manufacturing.
Material and resource efficiency ↑			
Carbon emissions intensity ↓			

MANUFACTURING ENGINEERING

THEME 4

Federated digital thread and ecosystem co-engineering

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Establish a federated digital thread that synchronizes design, validation and operations across partners.	**Connected design environments** — Shared digital platforms enable joint design of layouts, automation logic and equipment models across OEMs and suppliers. — Data exchanged securely within digital environments. — Early standards for interoperability and data governance reduce rework and design latency.	**Collaborative digital twin networks** — Connected digital twins synchronize design validation and process changes across partners in real time. — Collaborative models ensure cross-enterprise interoperability. — The digital thread expands from internal product lifecycle management (PLM) to ecosystem platforms.	**Co-evolving ecosystem engineering** — Federated ecosystems co-simulate and orchestrate adaptive factory twins across networks. — Multi-party models maintain synchronization, autonomous operations and decision-making.
Design lead time ↓			
Design cycle time ↓			

MANUFACTURING ENGINEERING | CASE STUDY

Siemens Numerical Control (SNC)

Accelerating flexible manufacturing with digital twins

Challenge	Solution	Impact
SNC, Nanjing, China faced rising market volatility and product variability, increasing manufacturing complexity and hindering closed-loop optimization. Traditional line design was slow and inefficient, limiting flexibility and impacting lead times, productivity and responsiveness.	To address these issues, SNC implemented a digital twin solution integrated with lean methodology, achieving 100% coverage in line design. The approach enabled virtual commissioning and rapid design verification, while optimizing daily operations through Plan-Do-Check-Act (PDCA) cycles and continuous improvement. This closed-loop system bridged production design and operations, ensuring flexibility and real-time adaptability.	The digital twin-led transformation significantly improved manufacturing agility and responsiveness by accelerating design, reducing complexity and enabling closed-loop optimization across operations, delivering: – 78% reduction in delivery lead time. – 61% faster design verification. – 14% improvement in cycle efficiency.

> **We call our Nanjing facility a digital-native factory. It was designed, tested and optimized in the virtual world before a single brick was laid. This enabled faster construction, cost efficiency and delivery under pandemic conditions. Combining global manufacturing expertise with local insight and a digital-first mindset, we optimize operations, making it one of our most efficient and flexible factories.**
>
> Cedrik Neike, Member of the Managing Board, Siemens;
> Chief Executive Officer, Digital Industries

3.3 Product development

Product development today is largely sequential and siloed, with disconnected design, engineering and manufacturing workflows. Late discovery of feasibility, cost and sustainability issues drives rework, slows iteration and extends time to market as product complexity increases. **Adaptive product innovation** defines the future that connects design, engineering and manufacturing in a continuous learning loop, enabling faster innovation, sustainable design and regenerative product lifecycles.

PRODUCT DEVELOPMENT

THEME 1 Closed-loop, model-based product lifecycle engineering

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Build a digital-first, AI-driven engineering environment that shortens design cycles, reduces physical prototyping and enables adaptive, high-performance products.	**Digital foundations for smart engineering** — Model-based systems engineering (MBSE) connects design, simulation and manufacturing. — AI-powered 3D digital twins validate designs virtually before concept freeze, reducing early physical prototypes. — Unified digital models, with AI checks ensure manufacturability review and design traceability.	**Intelligent, data-driven co-engineering** — Product and process twins link design, production and service. — AI simulates performance, cost and reliability, reducing physical prototypes and through virtual validation. — Real-time feedback from operations refines design continuously.	**Self-evolving engineering ecosystems** — Generative and self-learning AI integrate product, process and supply-chain twins within a cross-company PLM ecosystem, incorporating partner and end-customer data to optimize design iterations virtually and accelerate sustainable innovation at scale.
Engineering throughput ↑			
Asset productivity ↑			

PRODUCT DEVELOPMENT

THEME 2 AI-driven generative and circular design ecosystem

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Enable AI-driven circular design ecosystems that optimize performance, cost and sustainability through continuous feedback.	**Generative design foundations** — Generative design platforms optimize geometry, materials and cost. — Sustainability metrics embedded in early design. — Virtual validation ensures manufacturability and compliance.	**Circular design intelligence** — AI design agents co-create and test design variations across performance, cost and carbon. — Digital product passports track materials, lifecycle and circularity data. — Immersive digital twins validate complete product impact.	**Regenerative design ecosystems** — Agentic AI autonomously evolves regenerative product families. — Designs adapt to operational feedback and circular supply flows. — “Design-to-regenerate” becomes the standard, balancing performance, resilience and sustainability.
Design lead time ↓			
Material and energy efficiency ↑			

THEME 3

Software-defined and AI-driven product ecosystems

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Transform products into adaptive, software-defined systems that continuously optimize performance and unlock "product-as-a-service" revenue models.	**Software defined foundations** — Software-defined architectures decouple hardware from software. — Over-the-air (OTA) updates enable feature upgrades and tuning post-delivery. — Embedded digital twins monitor performance across the product fleet.	**AI-enabled adaptive products** — Integrated software-hardware platforms use AI-driven control and predictive analytics to refine performance continuously. — Edge-to-cloud learning enables adaptive updates.	**Autonomous product ecosystems** — Autonomous, self-optimizing product ecosystems evolve in real time. — AI orchestrates feature evolution, maintenance and service delivery. — "Product-as-a-service" drives lifecycle value.
Product lifecycle value ↑			
Annual recurring revenue ↑			

PRODUCT DEVELOPMENT | CASE STUDY

Hithium and Electroder

Digital platform + AI: next generation of battery cell development

Challenge	Solution	Impact
At Hithium, battery cells for energy storage must meet high performance and manufacturability standards, but trial and error R&D slows innovation and creates waste, driving the need for AI-enabled, simulation-driven battery development.	Hithium leveraged Electroder's AI-driven design automation platform combining advanced battery cell modelling, simulation-based virtual validation and a large language model enabled interface. The solution automatically generated relevant cell design options with essential targets for energy storage applications, validated performance digitally and enabled intuitive human-machine interaction to support faster, data-driven R&D decision-making.	The initiative accelerated battery cell development, improved first-time design success, enhanced design reliability and reduced R&D iteration cycles. It enabled broader adoption of advanced digital tools across engineering teams. Impacts included: – 2.5× faster battery cell development. – 36% increase in first-time design hit rate. – 30% rise in workforce adoption of advanced R&D tools.

> **Through this collaboration, we are redefining battery cell development for energy storage. Combining Electroder's AI simulation with Hithium's cell engineering shows innovation can be faster, scalable and inclusive shifting R&D from trial-and-error to intelligence and empowering broader teams.**
>
> Dean Xu, Chief AI Officer, Hithium and Luke Hu, Chief Executive Officer, Electroder

3.4 Supplier and engineering quality

Supplier engineering and quality is largely reactive due to fragmented data, manual inspections and minimal multi-tier visibility. **Cognitive supplier engineering networks** redefine assurance through predictive intelligence, digital twins and federated ecosystems enabling early defect prevention, continuous validation of conformance and manufacturability, and real-time alignment of engineering decisions across the value chain.

SUPPLIER AND ENGINEERING QUALITY

THEME 1

Proactive multi-tier quality assurance

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Build a resilient, multi-tier quality assurance network that detects risks early, ensures conformance and mitigates defects proactively across multi-tier suppliers.	**Digital foundations for smart assurance** — Distributed ledger-based provenance captures traceability for critical materials, across primary suppliers. — Limited risk simulations highlight potential failure points. — Predictive analytics flag high-risk shipments and compliance issues, but mitigation remains reactive.	**Scaled multi-tier predictive assurance** — Multi-tier traceability expands across suppliers and materials. — AI predicts quality deviations, ESG risks and supplier performance. — Prescriptive recommendations guide blocking, re-routing or corrective actions, strengthening ecosystem-wide assurance with human oversight.	**Autonomous assurance networks** — Agentic AI autonomously orchestrates supplier assurance end-to-end, including monitoring, rerouting or replacing suppliers based on real-time risk. — Secure, distributed assurance fabric ensures ecosystem-wide visibility, continuous self-correcting network with minimal human intervention.
Multi-tier defect detection lead time ↓			
Supplier conformance rate ↑			

SUPPLIER AND ENGINEERING QUALITY

THEME 2

Digital design assurance

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Ensure right-first-time supplier part and process design using AI-driven manufacturability, tolerance and quality validation before physical build.	**AI-enabled tolerance and defect prediction pilots** — Generative AI predicts tolerance stack-ups early in supplier parts. — Digital threads connect supplier computer-aided design with quality management systems (CAD/QMS) for manufacturability checks. — Insights drive quality gate readiness but still require manual rework.	**Continuous manufacturability validation** — AI continuously validates supplier part conformance before build. — Models verify process-capability, tolerance adherence and quality drift. — Real-time checks recommend corrective supplier actions.	**Autonomous design-manufacturing co-simulation** — Agentic AI validates manufacturability feasibility using shared digital parameters predictive drift detection. — AI assists deviation management by adjusting design parameters, tolerances and production sequences, translating design requirements into machine instructions before parts enter production.
Virtual design validation accuracy ↑			
Design change cycle time ↓			

SUPPLIER AND ENGINEERING QUALITY

THEME 3

Federated quality and innovation networks

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Create secure, collaborative supplier ecosystems to jointly assure quality, validate compliance and continuously improve robustness.	**Secure, shared learning pilots** — Federated learning pilots allow suppliers and OEMs to collaborate on defect patterns without sharing sensitive data. — Early shared digital twins support limited joint validation, but insights remain confined to specific issues and a small set of partners.	**Network-wide federated quality intelligence** — Federated AI scales up across supplier networks, enabling standardized learning from distributed data without compromising confidentiality. — Ecosystem models simulate quality, sustainability and compliance risks across tiers, with human oversight guiding approvals and mitigation.	**Autonomous supplier co-innovation ecosystems** — Agentic ecosystems autonomously share insights, validate quality and negotiate process or design trade-offs across suppliers. — Co-innovation networks continuously adapt designs and processes in real time enhancing resilience and sustainability, with minimal human coordination.
Supplier defect rate ↓			
Innovation cycle time ↓			

Volvo cars

Towards more sustainable EV batteries through transparency and data analysis

Challenge	Solution	Impact
Volvo Cars sought greater transparency and traceability across EV battery supply chains to strengthen supplier engineering oversight, quality assurance, sustainability and go beyond regulatory compliance.	Volvo Cars, working with Circulor, implemented a digital battery passport using private permissioned blockchain, configurable data verification and machine learning. The solution connected millions of supply-chain data points, enabled immutable traceability of critical raw materials, verified carbon footprint and recycled content and detected anomalies. The passport was first launched with the EX90 and embedded into production systems.	The digital battery passport strengthened transparency, trust and governance across Volvo Cars' EV battery supply chain by embedding verified data into core production processes and scaling up traceability globally, enabling: – End-to-end traceability of critical raw materials across electrified vehicles. – Verified carbon footprint and recycled content at scale. – Improved supplier oversight, quality governance and stakeholder transparency.

4 Supply chain network | Ecosystem

Supply chains are evolving into adaptive ecosystems that anticipate disruption and rebalance flows across partners and networks.

Supply chain networks are evolving from linear, transactional systems into intelligent, adaptive ecosystems with real-time visibility and predictive agility. AI-driven analytics, digital twins and autonomous logistics enable these networks to anticipate disruption, optimize flows and synchronize production with demand across global operations. Rather than reacting to change, frontier supply chains continuously adapt using data from suppliers, factories and customers to orchestrate decisions in real time. Human roles shift towards strategic oversight, scenario design and resilience planning. This transformation is foundational to competitiveness in an era where speed, sustainability and adaptability define long-term success.

4.1 Supply chain and network planning

Traditional supply chain planning struggles to keep pace with volatility, as static plans and delayed signals prevent coordinated response across the network. This slows response to disruptions. The future is **self-balancing supply networks** where risks are sensed early, scenarios are simulated and decisions are optimized in real time through digital twins, predictive planning and autonomous agents.

SUPPLY CHAIN AND NETWORK PLANNING

THEME 1 **Adaptive network optimization and disruption management**

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Build an adaptive, AI-ready supply chain network that senses disruptions early and reconfigures networks for resilient, cost-effective operations.	**Digital foundations for network visibility** — Digital twins unify supplier, production and logistics data for a single network view. — Real-time monitoring highlights delays, bottlenecks and capacity constraints. — What-if simulations support rapid disruption impact checks using pre-defined scenarios.	**AI-driven network optimization** — AI suggests alternate routes, sourcing strategies and inventory placements. — Predictive models anticipate supplier risks, transport delays and demand swings. — Dynamic scenarios compare cost, service and resilience trade-offs.	**Autonomous, self-balancing supply networks** — Learning twins automatically rebalance materials, capacity and sourcing. — AI continuously optimizes network flows based on real-time conditions. — Networks self-correct disruptions with minimal planner intervention.
Response speed ↑			
Cost-to-serve ↓			

SUPPLY CHAIN AND NETWORK PLANNING

THEME 2 Connected and intelligent fulfilment networks

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Establish a synchronized, resilient and customer-adaptive fulfilment network that unifies partners, channels and logistics to enable faster decisions and increasingly autonomous fulfilment.	**Connected visibility** — Unified visibility across suppliers, transport, warehouses and channels. — Multi-tier traceability tracks material movement and triggers real-time alerts for deviations and high-risk exceptions. — Shared dashboards improve coordination; recovery remains manual.	**Optimized omni-channel operations** — Integrated systems unify transport, warehouse and last-mile activities. — AI continuously optimizes fleet, labour, dock scheduling and channel capacity for best service and cost outcomes — Digital thread accelerates cross-functional decision-making.	**Autonomous, customer-adaptive fulfilment** — Fulfilment networks sense demand shifts, supply risks and disruptions and self-adjust in real time. — AI orchestrates inventory, routing, picking, replenishment and transport end-to-end. — Exceptions are predicted and resolved across partners before they impact service or cost.
End-to-end traceability ↑			
Capacity utilization ↑			

SUPPLY CHAIN AND NETWORK PLANNING

THEME 3 Predictive demand shaping and insight-driven integrated business planning (IBP)

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Create a predictive, insight-driven planning environment where demand, supply and finance continuously synchronize to optimize enterprise performance.	**Integrated, data-enhanced planning cycles** — Demand, supply and finance planning run on unified platforms. — Forecasts rely on historical trends and basic external signals, such as promotions, seasonality and macro trends. — Cross-functional cycles reduce manual reconciliation.	**Predictive, scenario-driven IBP** — Predictive analytics improve forecast reliability and demand sensing. — AI recommends inventory, production and pricing adjustments. — Scenarios quantify financial trade-offs across decisions.	**Autonomous, real-time enterprise orchestration** — AI synchronizes operational and commercial decisions end-to-end. — Plans self-adjust in real time based on demand, cost and margin shifts. — IBP becomes continuous, self-optimizing and profit aware.
Forecast accuracy ↑			
Margin impact ↑			

Unilever

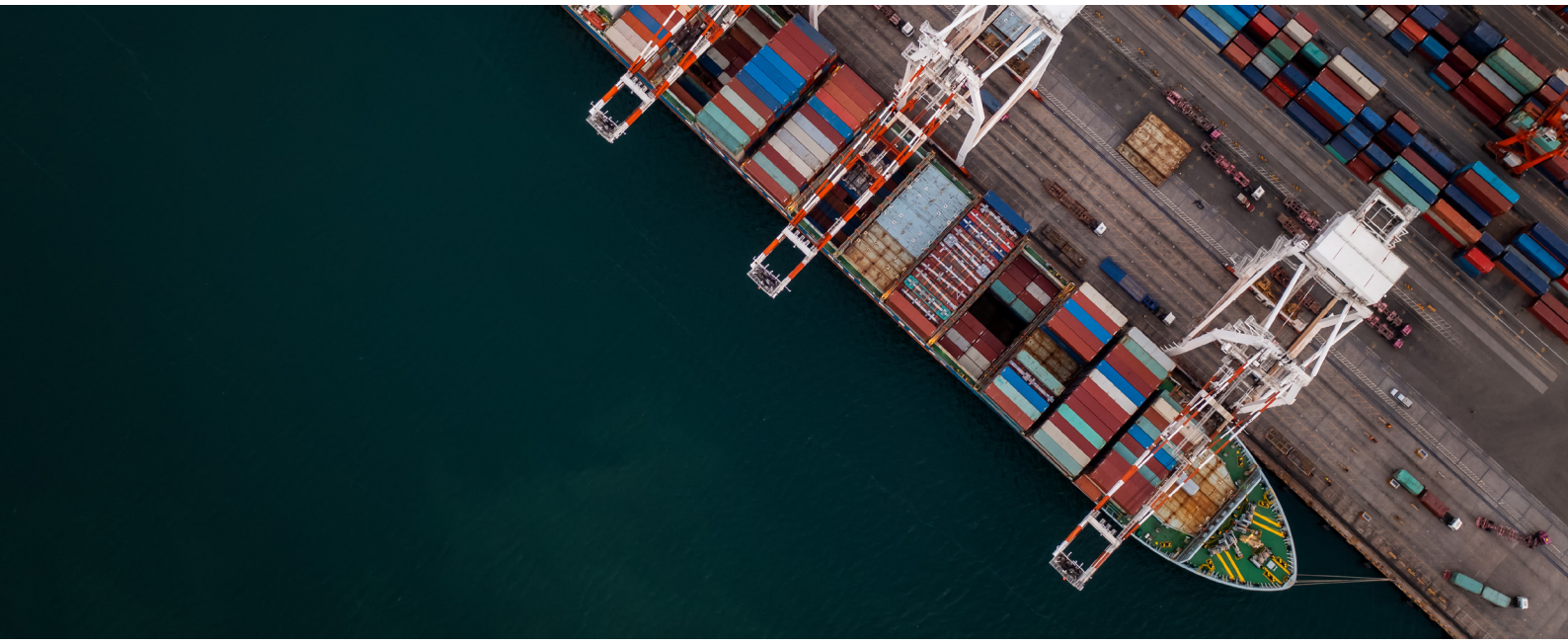
Smart scheduling and delivery optimization

Challenge	Solution	Impact
Unilever's Hefei FTC distribution centre faced volatile e-commerce demand and complex parcel decisions, where manual planning led to excess inventory, slow response times and rising logistics costs.	The company implemented two solutions: 1. An inventory system – powered by AI and machine learning – that integrates 12 data sources and analyses 10+ demand and performance variables to automate real-time replenishment and production decisions; in turn, improving stock balance, lead times and service levels. 2. A dynamic auto parcel optimization engine that uses real-time order data and 100+ packaging parameters to simulate scenarios and recommend cost-efficient bundling and shipping methods.	The transformation enhanced overall operational agility and efficiency in the following ways: – 39% improvement in SKU forecast accuracy. – 75% reduction in slow-moving stock. – 24% reduction in logistics cost per order.

> **Our commitment to innovation is rooted in serving consumers faster, smarter and more reliably. The factory-to-consumer site in Hefei shows how smart scheduling and AI-powered delivery optimization are transforming fulfilment, enabling us to respond rapidly to changing demand and consistently deliver the right products with greater speed. By combining advanced technology with deep consumer insight, we are building agile, collaborative supply chains designed to perform at scale in an increasingly dynamic market.**
>
> Graham Sommer, Global Head of Customer Operations, Unilever

4.2 External logistics

External logistics today remain fragmented, with carriers, warehouses and transport partners operating on disconnected systems that limit visibility and slow down response. Routing, tracking and issue resolution drive higher cost-to-serve and inconsistent delivery performance. The future is a **dynamic external logistics network**: AI-enabled, connected and continuously optimizing through real-time data, risk prediction and multimodal networks to improve service, resilience and sustainability.



EXTERNAL LOGISTICS

THEME 1

AI-driven logistics orchestration and control tower

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Build an intelligent logistics network that unifies end-to-end visibility, real-time decision-making and synchronized execution across the operational layer (transport, warehouses, carrier, partners and production).	**Foundational visibility and issue detection** — Consolidate data across the operational layer into a unified view. — Early-warning alerts flag delays, missed pickups, long dwell times, route deviations and capacity issues. — Rapid demand- and disruption-based scenario checks to assess delivery impact.	**AI-guided logistics decision-making** — AI recommends optimal routes that balance cost, speed, reliability and sustainability. — The operational layer synchronizes schedules and execution from a shared logistics plan. — Predictive adjustments smooth flows before bottlenecks occur.	**Autonomous logistics control tower** — AI automatically adjusts schedules, loads and routing as conditions change. — Network flows self-balance across the operational layer with minimal human input. — End-to-end orchestration becomes continuous, adaptive and cost-optimal.
Cost per shipment ↓			
On time in full ↑			

THEME 2

Circular logistics and reverse-flow orchestration

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Enable intelligent circular flow orchestration to maximize recovery, reuse and recycling across the logistics network.	**Structured reverse logistics** — Returned goods and reusable assets tracked across collection, repair and recovery points. — AI classifies items for reuse, repair, refurbishment or recycling. — Sustainability metrics are captured for each return cycle.	**Intelligent circular flow planning** — Visualizes material lifecycles and recovery potential end-to-end. — AI predicts return volumes and identifies the most valuable recovery paths. — Repair and recycling operations are optimized for cost and turnaround.	**Autonomous circular ecosystems** — Forward and reverse logistics flows balance automatically with AI. — Materials circulate between partners with minimal manual coordination. — A self-sustaining circular network minimizes waste and maximizes recovery.
Material recovery rate ↑			
Return cycle time ↓			

EXTERNAL LOGISTICS | CASE STUDY

Port of Los Angeles

Optimizing supply chain logistics using quantum computing

Challenge	Solution	Impact
Rising cargo volumes strained operations at the Port of Los Angeles, with long truck waits, inefficient crane movements and underused assets exposing the limits of rule-based scheduling.	A hybrid quantum computing-based optimization engine was deployed to address large-scale, combinatorial scheduling challenges. The solution evaluated a vastly expanded solution space, simulating over 100,000 cargo-handling scenarios. By dynamically optimizing truck-to-crane assignments under real-time constraints, the system generated near-optimal schedules that classical methods could not efficiently achieve.	The initiative delivered significant efficiency and reliability gains by optimizing terminal operations and throughput, resulting in: – 40% higher crane utilization. – 60% more container moves per crane. – 2 hours reduction in truck wait time.

4.3 Customer integration

Customer signals, product usage data and service insights remain scattered across disconnected systems, with forecasts relying on historical trends and responses remaining slow and reactive. OEM-customer relationships are largely transactional, with limited lifecycle visibility and inconsistent engagement. Customer integration is becoming a **connected experience hub**, where real-time signals guide operations, enabled by connected product twins, lifecycle control towers and autonomous multi-agent systems that synchronize demand, service and innovation between manufacturers and customers.

CUSTOMER INTEGRATION

THEME 1

Connected demand and delivery networks

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Build a responsive demand and delivery network that senses customer needs early and synchronizes production and supply accordingly.	**Predictive demand sensing** — AI strengthens visibility into customer demand, enabling more accurate planning and service levels. — Customer demand signals flow directly into inventory, warehouse and delivery plans to reduce stockouts and improve responsiveness. — Early real-time coordination supports faster customer-focused decisions.	**Adaptive demand orchestration** — AI orchestrates coordinated adjustments across demand, production, inventory and logistics beyond isolated optimizations. — Continuous predictive-prescriptive planning enables rolling reforecasts and auto-recommendations through the day. — Networks proactively anticipate demand shifts, supply risks and cost/carbon fluctuations and adjusting ahead of time.	**Autonomous demand webs** — Multi-agent AI systems balance customer demand, supply capacity and service priorities across regions and channels. — Customer behaviour, shipment costs and sustainability goals self-optimize with minimal manual intervention. — A living demand ecosystem ensures continuous alignment between customer needs and operational execution.
Service-level adherence ↑			
Forecast accuracy ↑			

CUSTOMER INTEGRATION

THEME 2 Integrated service and performance partnerships

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Deliver zero-downtime performance and cost-efficient service through connected assets and shared lifecycle intelligence.	**Connected product insights** — Product usage, operating conditions and fault signals enable predictive maintenance. — Real-time alerts help service teams to prevent failures and reduce unplanned downtime. — Data-driven and service history improves root-cause analysis.	**Lifecycle control tower** — AI detects anomalies and recommends remote adjustments, which technicians approve and execute. — Lifecycle control towers enable fleet-wide monitoring and coordinated interventions. — OEM-customer teams align on shared KPIs to improve uptime and responsiveness.	**Autonomous performance ecosystems** — Assets self-tune and self-correct within guardrails, with humans overseeing exceptions. — Failures are proactively avoided through autonomous adjustments and embedded physical AI. — OEM and customer operations form a self-optimizing, zero-downtime ecosystem.
Asset uptime ↑			
Service response time ↓			

CUSTOMER INTEGRATION

THEME 3 Unified engagement and experience platforms

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Create hyper-personalized, proactive experiences that strengthen loyalty and lifetime value across all touchpoints.	**Connected customer portals** — Consolidate service history, shipment tracking, support tickets and asset insights into one digital interface for customers. — Provide transparent updates and basic personalization, such as alerts or usage recommendations. — Streamline interactions by reducing dependence on multiple OEM touchpoints.	**Context-aware experience platforms** — Customer interactions evolve through AR, mobile and voice interfaces that adapt to real-time behaviour and operating context. — Behavioural analytics guide targeted recommendations, service reminders and personalized support journeys. — Experiences become multi-modal, consistent and responsive to the customer's role and intent.	**Agentic experience ecosystems** — AI copilots interpret conversational, operational and contextual cues to anticipate intent and co-orchestrate decisions with customers. — Experience journeys continuously evolve based on real-time learning, ensuring hyper-personalized service and engagement. — Customer and OEM agents collaborate seamlessly to resolve issues, run operations and plan future needs.
Customer query resolution time ↓			
Customer lifetime value ↑			

CUSTOMER INTEGRATION

THEME 4

Collaborative value and co-creation models

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Accelerate shared value creation by enabling customers to co-design, co-simulate and co-develop solutions with OEMs.	**Digital co-design tools** — Customers configure products, simulate performance and provide early design input using interactive 3D or AR tools. — Early iterations cut engineering rework and shorten time-to-spec. — Tighter feedback loops improve accuracy and design confidence.	**Industrial metaverse collaboration** — OEMs and customers jointly simulate design, performance and carbon lifecycle impacts; and conduct virtual pre-dispatch inspections in immersive metaverse environments. — Complex engineering concepts are validated collaboratively in digital testbeds. — Immersive collaboration accelerates development cycles and commercialization.	**Federated co-creation ecosystems** — OEMs, partners and customers co-innovate in secure shared spaces with controlled data and IP sharing. — Autonomous design agents explore multiple solution paths and recommend optimal concepts. — Federated ecosystems enable real-time monetization of new products and services, unlocking growth.
Time to market ↓			
Co-creation cycle time ↓			

CUSTOMER INTEGRATION | CASE STUDY

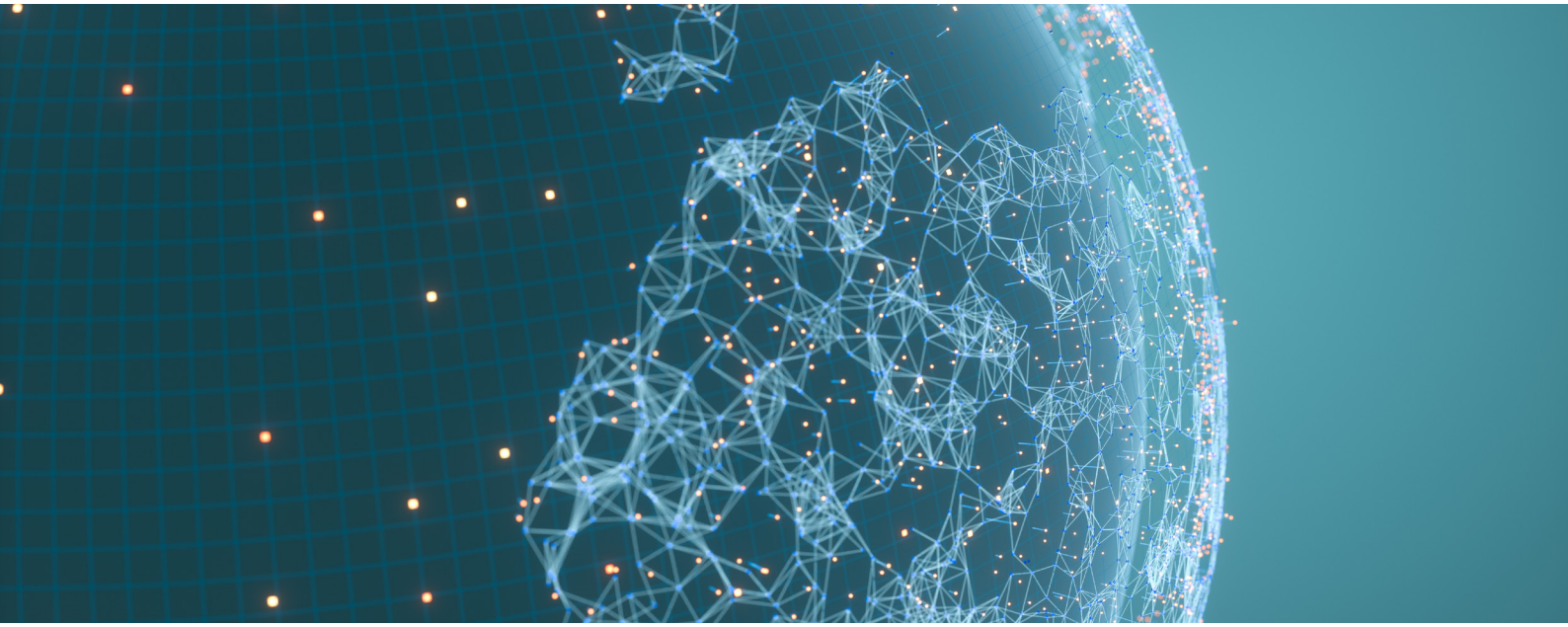
Midea

Closing the loop: turning customer feedback into autonomous quality improvement

Challenge	Solution	Impact
Midea's Si Racha plant struggled to manage over 1,000 annual complaints from 80 service centres across 40 countries. Manual processes caused delays of up to 30 days and heavy reliance on judgement, limiting consistent and timely resolution and highlighting the need for faster, data-driven quality response.	As highlighted in the World Economic Forum's *Global Lighthouse Network 2026* report, to address these issues, Midea deployed an AI-driven system that automated the end-to-end process linking voice-of-customer (customer feedback) to voice-of-process (production quality improvements). Customer feedback was centralized and integrated with QMS to create a closed data loop, while advanced graph-matching linked complaints to responsible units and LLMs generated root causes and corrective actions validated by engineer chatbots. This enabled proactive quality control with faster, more accurate responses and less manual effort.	The transformation delivered measurable impact by connecting customer signals directly to production, reducing manual checks and elevating global quality standards while turning feedback into foresight, resulting in: – Quality issue-to-action plan lead time cut to 1 day. – 32% reduction in customer complaints. – 43% lower defect rates.

4.4 Supplier collaboration

Supplier collaboration is constrained by limited multi-tier visibility, manual coordination and late risk detection, slowing response and agility. The future is connected and cognitive supplier ecosystems that use digital twins and AI to synchronize capacity, risk, sustainability and innovation in real time.



SUPPLIER COLLABORATION

THEME 1

Collaborative production and capacity networks

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Build digitally connected production ecosystems that enable network partners to share data, anticipate risk early and co-create coordinated responses that strengthen resilience and performance.	**Digital foundations for network visibility** — Network partners use digital twins and shared dashboards to view capacity, inventory and disruption signals. — Coordination improves, but data exchange remains manual with risk signals monitored through performance metrics and incident reporting.	**Predictive and collaborative risk response** — AI detects weak signals early and simulates alternative production and supply scenarios.[7] — OEMs and suppliers jointly review insights to co-create mitigation and recovery plans. — Structured governance aligns on trade-offs, responsibilities and coordinated execution.	**Autonomous network-level orchestration** — Supplier ecosystems autonomously rebalance production based on real-time signals. — Agentic systems negotiate task sharing, reroute material flows and reallocate capacity, allowing factories to operate as synchronized nodes within a self-healing network.
Network response lead time ↓			
Supplier risk detection lead time ↓			

THEME 2

Collaborative innovation and design platforms

Evolutions of themes

Objectives	NOW (0-2 years)	NEAR (3-5 years)	NEXT (5+ years)
Enable suppliers and OEMs to co-develop materials, tooling and process innovations through shared design spaces and virtual testbeds.	**Early co-development environments** — OEMs and strategic suppliers collaborate using shared simulation models and controlled IP environments. — Innovation cycles improve, but validation remains sequential and limited to a small set of partners.	**Networked virtual testbeds and continuous co-development** — Digital twins and virtual testbeds enable rapid experimentation with materials, tooling and processes across suppliers. — Co-development becomes continuous, with partners validating design and manufacturing changes in shared virtual environments.	**Autonomous co-innovation ecosystems** — Agentic systems autonomously exchange insights, validate new ideas and coordinate R&D activities across OEMs, suppliers and startups. — Innovation becomes distributed and adaptive, with federated platforms shortening development cycles and increasing innovation yield.
Co-development cycle time ↓			
Engineering rework ↓			

SUPPLIER COLLABORATION | CASE STUDY

Kappahl and Marimekko

Unlocking circular fashion: digital product passport

Challenge	Solution	Impact
Kappahl and Marimekko, Nordic fashion retailers with over 500 stores combined, took part in the first end-to-end textile digital product passport (DPP) pilot to prepare for upcoming European sustainability regulations. DPPs make product information transparent across origin, materials and lifecycle, to support circular business models. Acting early allowed both brands to move from theoretical planning to tangible implementation.	Working with TrusTrace and the Trace4Value consortium, the brands embedded GS1 digital link-compliant QR codes into over 3,000 garments, connecting each item to a secure digital record. As an existing TrusTrace user, one brand already had traceability up to Tier 3 suppliers, making collection significantly quicker than for a first-time setup. Implementation required coordination with label manufacturers and garment production factories to integrate serialized codes into production lines, enabling lifecycle transparency and future accessibility by recyclers and repairers.	The initiative deployed live, scannable DPPs across European retail and established a 125-datapoint protocol across nine categories, the most comprehensive textile-specific DPP protocol to date. Beyond the technical work, senior decision-makers became more engaged once products could be physically scanned, helping identify new opportunities for customer engagement and product storytelling.

5 Leadership and governance in intelligent operations

As operations become intelligent, leaders must steer complex systems while ensuring the resilience, integrity and trust of the digital infrastructure that enables them.

Leadership must extend beyond traditional oversight to governing increasingly autonomous operational systems. As decision-making becomes more data-driven and interconnected across enterprises and ecosystems, executives must balance speed, transparency and accountability in how systems operate and interact. At the same time, the growing digital backbone of industrial operations requires robust safeguards to ensure reliability and continuity. Together, leadership governance and system resilience form the foundation for scaling up intelligent operations responsibly.

5.1 Intelligent Operations Boardroom

The widespread integration of frontier technologies has elevated operational speed and resilience, while fundamentally changing how factories, networks and partners behave. The purpose of boards to provide oversight and strategic guidance has become more complex. Decisions extend beyond single functions, influencing results across teams, locations and time. C-suite leaders must look beyond metrics and learn to orchestrate complexity as a source of competitive advantage, whether through market adaptability, product variety or differentiated experiences.

In this evolving context, organizations are beginning to establish what can be described as an "Intelligent Operations Boardroom". This refers to a decision environment that brings together operational signals from across factories, enterprises and supply networks into a unified view for leadership. By integrating real-time data, digital twins and AI-driven simulations, it allows leaders to explore potential outcomes, understand system-wide effects and evaluate trade-offs before committing to strategic decisions.

Such capabilities become particularly important in periods of heightened volatility. As highlighted in Chapter 1 through the eight forces shaping industrial operations, geopolitical shocks, regulatory shifts and supply disruptions force leaders to make intertwined decisions on sourcing, capacity, energy exposure and customer commitments. A move to reduce risk in one region may create new vulnerabilities elsewhere. The challenge is not only to react faster but to evaluate second- and third-order effects. Traditional dashboards cannot deliver that foresight, nor reveal opportunities hidden in the operational tail, such as smaller suppliers and overlooked processes that can drive significant impact.

A move to reduce risk in one region may create new vulnerabilities elsewhere. The challenge is not only to react faster but to evaluate second- and third-order effects.

The Intelligent Operations Boardroom answers this need (see Figure 6). As a digital decision-making twin, it frames options, rehearses outcomes and logs decisions, giving leaders a shared enterprise context to view system-wide effects before committing. With real-time simulations and richer data at hand, boardroom judgement is expected to go beyond high-level synthesis. Leaders must probe deeper, challenge assumptions and make decisions with greater precision, transparency and accountability.[8,9]

FIGURE 6 **Evolution of the Intelligent Operations Boardroom**

	NOW (0–2 years) Better decisions, defensibly made	NEAR (3–5 years) Foresight across enterprise decisions	NEXT (5+ years) Autonomy without loss of control
Boardroom in action	— The boardroom consolidates signals into one coherent operational picture helping leaders evaluate decisions by exposing trade-offs and system-wide ripple effects. — Integrated scenario simulation and what-if analysis allow executives to test choices before execution.	— Increasing autonomy enables AI-driven decision-making twins that simulate second- and third-order effects across functions and partners. — Workflows and decision paths are redesigned for an AI-first operating model, clarifying where AI supports, recommends or decides — allowing leaders to evaluate trade-offs across resilience, cost, sustainability and risk before commitment.	— This reflects AI-first enterprise thinking, where redesigned workflows operate largely autonomously, coordinated by AI systems across plants, functions and partners. — The boardroom becomes the primary interface for steering autonomy, setting strategic objectives, defining priorities and guardrails.
Example	When a sudden trade restriction affects a key sourcing region – for example, geopolitical disruptions in the Middle East in March 2026 affecting the Strait of Hormuz shipping routes – leadership rapidly assesses exposure across suppliers, plants and customer commitments. Response options such as absorbing cost increases, shifting production or prioritizing specific markets are evaluated to stabilize operations and limit immediate disruption.	As similar disruptions recur, leaders examine how trade shocks may evolve extended restrictions, secondary supplier failures or regulatory spillovers. Alternative enterprise strategies such as regional rebalancing or supplier diversification, to strengthen resilience across a range of plausible futures are compared.	Rather than responding to individual trade disruptions, executives define acceptable exposure levels, service commitments and regional risk thresholds upfront. The board's focus shifts to shaping long-term advantage while intervening only when strategic limits are breached.

5.2 Cybersecurity by design

With the evolution of manufacturing systems, cybersecurity must become a foundational design imperative rather than a downstream technical concern. The proliferation of AI agents, autonomous robots and connected cyber-physical systems dramatically expands the attack surface, where vulnerabilities can cascade rapidly across operations, safety and quality. In environments defined by continuous machine-to-machine interactions and real-time decision loops, security failures no longer remain isolated; they proliferate at the speed of the system itself.

> **The proliferation of AI agents, autonomous robots and connected cyber-physical systems dramatically expands the attack surface, where vulnerabilities can cascade rapidly across operations, safety and quality.**

> Resilience and trust are forged not just in code, but in boardrooms and on factory floors, wherever leadership is willing to see security as a source of competitive advantage.

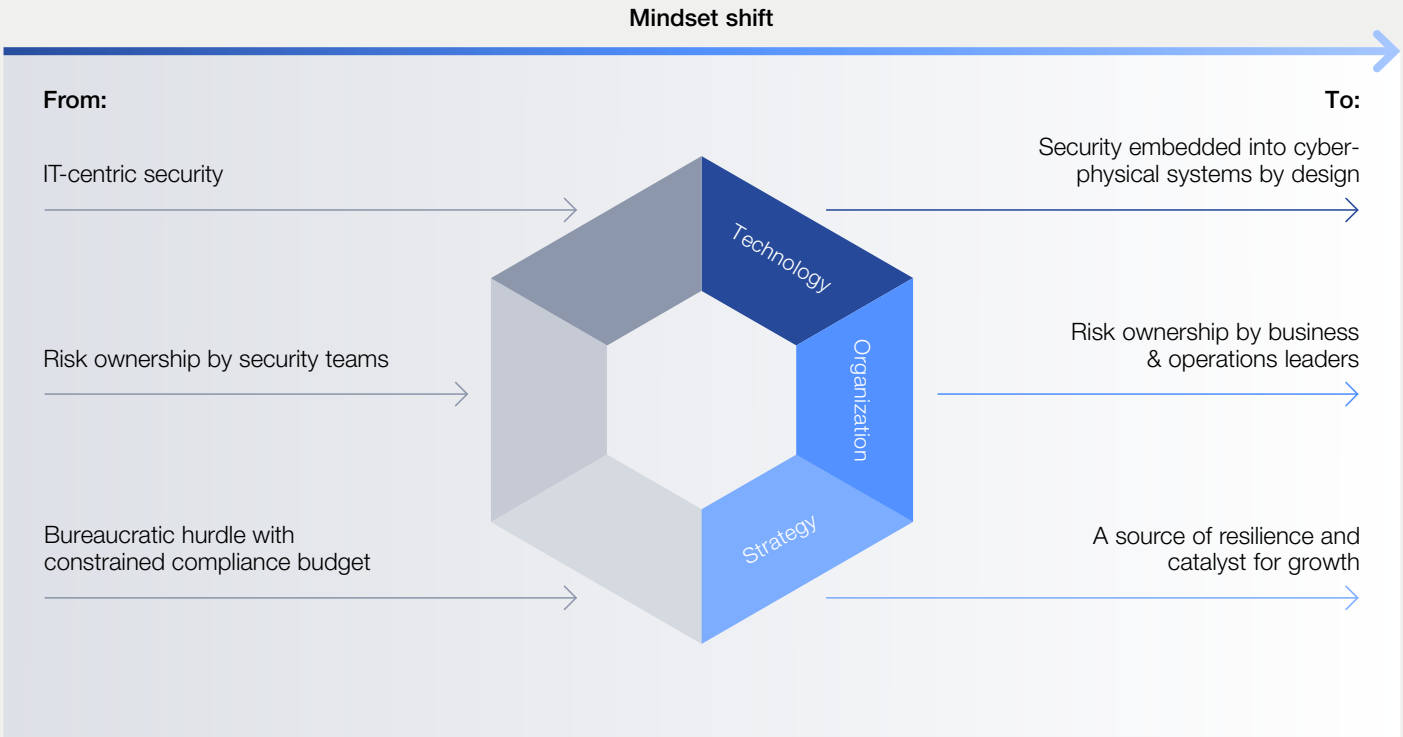
Yet despite the growing recognition of these risks, familiar failings persist. Security is too often bolted on as a non-functional extra, threat modelling is neglected and teams operate in isolation, with testing deferred until late in the game. These lapses are not mere abstractions.

Recent disclosures of critical vulnerabilities in connected vehicles from manufacturers such as Kia,[10] which enabled remote unlocking and tracking of vehicles already in the field, demonstrate how security gaps introduced during design can surface only after deployment. Equally, a 2025 cyberattack on Jaguar Land Rover's IT systems forced a weeks-long shutdown of UK production facilities, disrupting manufacturing operations and rippling through its global supply chain, illustrating the operational consequences of exploited security weaknesses.[11]

As frontier technologies mature, these failures become increasingly consequential. Threats such as data poisoning, adversarial sensor manipulation, agent identity spoofing and quantum-enabled decryption are no longer hypothetical edge cases; they arise directly from the speed, autonomy and interdependence of next-generation systems.

The architecture of cybersecurity must evolve to meet the demands of frontier technologies. Zero trust and layered defences, once the preserve of IT, are now being retooled for a world where legacy machinery shares the shop floor with autonomous agents and intelligent sensors. Encryption, once an afterthought, is fast becoming the lifeblood of industrial data flows. This is enabled by embedding security controls directly into cyber-physical architecture through secure device identities, authenticated machine-to-machine communication, integrity validation of models and control logic, and continuous monitoring of autonomous systems in operation. Yet, as industry specialists caution, the real battleground is organizational. Transformation depends on shifting mindsets, as illustrated in Figure 7.

FIGURE 7 **Securing the next frontier: mindset shifts for cyber-physical operations**



The mindset shifts illustrated in Figure 7 enable tailored solutions: for example, a manufacturer, facing the challenge of integrating AI and IoT, found success by involving operations teams in security governance, ensuring controls were relevant and adaptable rather than rigidly imposed. Early threat modelling, cross-functional collaboration and clear governance are no longer optional. In this new landscape, resilience and trust are forged not just in code, but in boardrooms and on factory floors, wherever leadership is willing to see security as a source of competitive advantage.

6 Way forward: leadership imperatives

Realizing the value of intelligent operations demands bold leadership to sequence capabilities and scale up autonomy across operations.

As manufacturing and supply chains move towards more autonomous operating models, progress is diverging sharply across industries and organizations. According to a global Accenture survey,[12] only about 25% of companies have begun their autonomy journey, embedding automation and AI more deeply across operations, while many others remain constrained by fragmented capabilities and manual decision-making. This growing divergence signals that the way forward will require more than incremental improvement. It requires a clear set of leadership imperatives that help organizations translate technological capability into sustained operational and financial impact.

The roadmap below outlines how leaders can sequence these imperatives to move from foundational readiness to scaled, network-level autonomy regardless of where they start.[13]

FIGURE 8 | **Leadership roadmap for next-generation operations**

#1

Strengthen process discipline: Stabilize, simplify, digitize before autonomy

- Autonomous capabilities cannot compensate for inconsistent execution
- Core processes must be stabilized, simplified and digitized before advanced automation is layered on

#2

Focus on decision-critical data: Enable decisions, not data perfection

- Prioritize decision-critical data, ensuring reliability, interoperability and access across operations, rather than pursuing enterprise-wide data perfection

#3

Prioritize few, material use cases: Shift from pilots to financial line of sight

- Focus on a small number of use cases that materially improve responsiveness, resilience or cost transparency, with clear visibility into financial impact

#4

Strengthen the digital core with NEXT-first thinking: Scale up deliberately, avoid fragmentation

- Ensure data, analytics and AI inform decisions across functions, with NEXT-first sequencing guiding technology investments toward enterprise impact

#5

Reimagine human-machine collaboration*: From execution to orchestration and learning

- Shift human roles to orchestration, exception management and system learning, while machines take on optimization and execution at speed

#6

Scale autonomy with trust and sustainability: From localized autonomy to network operations

- Embed trust, accountability, sustainability and resilience into operations as autonomy scales up across sites and ecosystems

Note: *The World Economic Forum's Human-Machine Collaboration (HMC) initiative reinforces this shift by helping organizations prepare the workforce with the skills, capabilities and collaboration models needed to succeed alongside increasingly autonomous systems.

As autonomy increasingly scales up through ecosystem orchestration and platform-based models, leaders must also actively manage power imbalances and dependency risks. When control over critical platforms, data standards or decision logic concentrates with a small number of orchestrators, mid-tier suppliers and manufacturers risk being commoditized unless they retain differentiation, selective data control and a voice in ecosystem governance. How these dynamics are managed will shape not only adoption speed, but also how value is distributed across the ecosystem.

In the end, the leadership challenge is one of execution and choice. Whether embedding autonomy from the outset in new environments or integrating it incrementally across complex brownfield operations, the decisions that leaders make now will shape how effectively autonomy scales up over time.

Conclusion

Industrial operations are entering a defining decade of “intelligent operations”. The shift underway is not simply from manual to automated systems, but towards an operating logic built on intelligence, controlled autonomy and ecosystem-level coordination. As this report shows, future competitiveness will depend less on isolated technology adoption and more on the ability to orchestrate complex systems that continuously sense, learn, decide and adapt in real-world environments.

Progress, however, will not be linear. Early momentum has been driven largely by efficiency-focused, “type-1” gains, while the deeper challenge lies in inventing fundamentally new ways of working. As AI moves from controlled or simulated settings into complex, safety-critical operations, a period of recalibration and even disillusionment should be expected. Far from signalling failure, this phase is essential for redirecting investment, expectations and effort towards capabilities that can be trusted, governed and scaled up.

What will ultimately differentiate leaders is how they navigate this transition. The NOW–NEAR–NEXT horizon underscores that choices made today around data foundations, operating models, governance and talent will determine whether intelligence compounds over time or stalls in fragmented pilots. Leadership must therefore evolve from oversight to orchestration, enabling increasingly autonomous systems to deliver sustained value.

The next frontier of operations is already emerging, unevenly but unmistakably. Organizations that act with discipline and patience, aligning technology and operating models with leadership intent, will build more resilient, adaptive and sustainable industrial systems. Those that delay risk being overtaken by complexity they can no longer control. The opportunity ahead is not transformation as a one-time initiative, but intelligent operations as a continuously evolving capability. And as this capability evolves, the World Economic Forum’s *Next Frontier of Operations* initiative will continue to provide a collaborative platform to discuss these latest trends, co-create adoption approaches and accelerate the journey towards intelligent operations.

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Endnotes

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