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# The Digital Shift in Maintenance: Trends, Challenges, and Opportunities.

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## Abstract

The transition from traditional maintenance paradigms toward data-driven, intelligent asset management is redefining the role of maintenance in industrial strategy. This chapter introduces the digital shift in maintenance, positioning it as both a technological evolution and an organizational transformation. Building upon the foundations laid in *Digital Maintenance Management* (2022), it examines the accelerating convergence of operational technology (OT) and information technology (IT), and how emerging capabilities such as AI-driven diagnostics, digital twins, and cloud-edge architectures are reshaping decision-making and performance optimization. The chapter identifies key enablers—connectivity, standards, semantic interoperability, and governance frameworks—that support the scalable deployment of digital maintenance solutions. It also outlines persistent challenges including fragmented data ecosystems, skills gaps, cybersecurity threats, and the difficulty of aligning condition data with long-term investment decisions, the critical link between real-time condition monitoring and strategic asset value management. This introductory chapter serves to frame the structure of the book, offering a roadmap through the technological, organizational, and regulatory forces currently shaping maintenance transformation. It advocates for a layered, standards-based, and maturity-aligned approach to digitalization, recognizing that successful transformation is as much about culture and capability as it is about tools. By mapping key trends and tensions, the chapter sets the stage for deeper thematic analysis in subsequent contributions.

**Keywords:** Digital maintenance transformation, Asset Performance Management (APM), Asset Investment Planning (AIP), Digital twins, Industrial Internet of Things (IIoT), Maintenance standards and interoperability.

## 1. Introduction – Why Maintenance Is Undergoing a Digital Shift

Over the past two decades, maintenance has evolved from a cost-centered technical activity into a strategic function within industrial organizations. This transformation was first marked by the rise of operational reliability considerations when designing and analyzing maintenance, the use of condition monitoring, and the integration of maintenance into broader asset management systems. However, the current wave of digitalization represents a more fundamental shift: a redefinition of how asset health, risk, and value are assessed, managed, and optimized. It is not merely a question of adopting new tools, but of restructuring the very logic of maintenance within a connected, intelligent ecosystem.

In 2022 I published the book *Digital Maintenance Management*, (Crespo Márquez, 2022) the idea was to lay a groundwork for understanding how digital technologies—from new

EAM-APM-AIP platforms to AI based predictive analytics—were reshaping practices and roles. Since then, this landscape has matured rapidly. Emerging technologies such as digital twins, edge computing, and artificial intelligence (AI) are no longer confined to pilot programs but are increasingly embedded in operational workflows. According to the Digital Twin Consortium (2022), digital twins are being adopted as core components of real-time diagnostics and simulation environments in asset-intensive sectors. At the same time, global disruptions—supply chain volatility, climate imperatives, energy constraints, and skills shortages—have forced organizations to reassess the resilience, agility, and intelligence of their maintenance strategies. As highlighted by the World Economic Forum (2023), these systemic pressures are accelerating digital transformation across industries, with maintenance playing a pivotal role in operational resilience.

This chapter introduces the central thesis of the book: that digital maintenance is not an optional innovation but a necessary evolution to ensure sustainable performance, operational reliability, and value preservation in asset-intensive environments. It explores how the digital shift is underpinned by multiple interrelated forces. First, technological enablers (IIoT, AI/ML algorithms, etc.) provide the capability to acquire, contextualize, and act upon real-time data. Second, the growing importance of standards— uch as ISO 55000, IEC 81346 (IEC, 2022), RAMI 4.0, and ISO/IEC 42001 for AI governance (ISO/IEC, 2023)—ensures consistency, interoperability, and scalability. Third, decision-making is increasingly supported by integrated platforms that combine operational data with long-term planning, exemplified by the rising adoption of Asset Investment Planning (AIP) frameworks (Copperleaf Technologies, 2021).

Yet, the path toward digital maintenance excellence is neither linear nor uniform. Many organizations face challenges of fragmented data, incompatible systems, cybersecurity exposure, and workforce resistance or skill mismatches. Moreover, digital maturity varies widely across sectors and geographies, making it essential to consider cultural, organizational, and infrastructural readiness alongside technical capability. The Digital Readiness Framework developed by GFMAM (2021) emphasizes that successful transformation depends not only on technology, but also on leadership, governance, and integration capacity.

Lastly, as AI plays a growing role in predictive maintenance and anomaly detection, questions of transparency, classification, and responsible use become essential. The OECD Framework for the Classification of AI Systems (OECD, 2021) provides valuable guidelines to support ethical and traceable deployment of intelligent systems in industrial settings.

This introductory chapter sets the stage for a deeper exploration of the technologies, standards, case studies, and management approaches that define the digital maintenance frontier. It offers a roadmap for practitioners, researchers, and policymakers to understand not just *what* is changing, but *why* it matters—and *how* to respond strategically. The shift toward digital maintenance is not just about doing maintenance differently—it is about enabling organizations to think, decide, and adapt at a fundamentally new level of intelligence.

## 2. The Drivers of Digital Transformation in Maintenance

The digital transformation of maintenance is not an isolated phenomenon—it is the outcome of converging technological, economic, and organizational forces that are reshaping the way industrial assets are managed. While predictive maintenance and condition monitoring laid the groundwork for smarter operations, the current wave of innovation goes far beyond isolated technologies. It represents a systemic shift in how data, systems, and decision-making interact to deliver reliability, performance, and long-term value.

### 2.1 Technological Enablers: From Sensing to Intelligence

At the heart of digital maintenance lies the ability to capture, interpret, and act upon data. The emergence of the Industrial Internet of Things (IIoT) has enabled real-time data acquisition at scale, allowing sensors, actuators, and smart components to feed continuous streams of condition data into central systems. This has shifted the role of maintenance from reactive to predictive, and increasingly toward prescriptive models where interventions are optimized not only for technical risk but also for business impact.

Beyond connectivity, artificial intelligence (AI) and machine learning (ML) now play a critical role in detecting anomalies, forecasting failures, and recommending actions. These systems require large volumes of high-quality, contextualized data to generate insights—a capability supported by digital architectures that integrate IT and OT layers, including cloud-edge computing models and the use of asset data platforms.

Moreover, digital twins have become a cornerstone of advanced maintenance strategies. According to the Digital Twin Consortium (2022), digital twins provide a synchronized digital representation of a physical asset, enabling simulation, diagnostics, and performance optimization. Their growing deployment reflects a broader push toward model-based decision-making, where data is not only descriptive but actionable.

### 2.2 From Technical Standards to Semantic Interoperability

The scalability and reliability of digital maintenance systems depend heavily on the use of shared standards. The ISO 55000 series has established a common vocabulary and set of principles for asset management, including the alignment of maintenance activities with value creation. Complementary standards such as ISO 14224 (reliability data), IEC 81346 (system structuring), and ISO 10303 (product data exchange—STEP) provide foundational models for structuring, labeling, and exchanging asset information.

Recent frameworks such as RAMI 4.0 and the Industrial Internet Reference Architecture (IIRA) have extended this foundation by describing how industrial systems should be modeled and integrated across their lifecycle stages. They also provide templates for layered digital architectures, connecting physical assets with logical representations, business processes, and platform services. These architectures are particularly important for ensuring interoperability across vendors and systems, and for enabling digital continuity over time.

The emergence of the Asset Administration Shell (AAS) as a standardized data model in Industrie 4.0 ecosystems reinforces this shift toward semantically interoperable and machine-readable maintenance data. The AAS defines how asset-related information can be described, stored, and exchanged across the value chain, allowing for more flexible, composable, and automated maintenance processes.

## 2.3 From Operational Constraints to Strategic Pressures

The push toward digital maintenance is also driven by macroeconomic and strategic pressures. Organizations face growing demands for asset availability, operational efficiency, cost control, and sustainability. In parallel, the complexity of asset portfolios and the consequences of unplanned downtime are increasing. These pressures have made it essential to move from reactive and time-based approaches to dynamic, data-informed strategies.

Sustainability goals and regulatory frameworks—such as the EU Green Deal or global ESG reporting standards—have further increased the focus on asset lifecycle management. Maintenance is no longer a purely technical function; it is part of an integrated strategy for extending asset life, reducing energy use, and minimizing environmental impact.

Furthermore, the COVID-19 pandemic and subsequent global disruptions exposed the vulnerabilities of traditional maintenance practices reliant on manual inspections and rigid schedules. Organizations have accelerated digital adoption not just for efficiency, but also for resilience and remote operability. As noted by the World Economic Forum (2023), maintenance digitalization is now seen as a core enabler of industrial transformation and competitiveness.

## 2.4 From Operational Optimization to Value-Driven Planning

The role of maintenance is increasingly shifting from operational support to strategic value generation. This evolution is enabled by platforms that link asset health with financial and risk-based planning. Asset Performance Management (APM) systems incorporate condition data, failure models, and reliability analytics to prioritize interventions and optimize maintenance plans. Meanwhile, Asset Investment Planning (AIP) platforms add a long-term dimension, enabling organizations to evaluate trade-offs between performance, risk, and cost over asset life cycles.

According to Copperleaf Technologies (2021), AIP systems help infrastructure managers align investment decisions with business objectives, incorporating maintenance insights into multi-year capital planning. This integration closes the loop between operational data and enterprise strategy, reflecting the maturity levels described in the GFMAM Digital Readiness Framework (GFMAM, 2021).

Ultimately, these capabilities support the transition from maintenance as a cost center to maintenance as a value enabler. They empower organizations to manage their asset base more intelligently, respond to uncertainty with agility, and drive transformation at both technical and managerial levels.

# 3. The Landscape in 2022 – A Recap

When I published the book *Digital Maintenance Management* (Crespo Márquez, 2022)I did an effort in conceptualizing the evolution of maintenance practices within the digital era. Central to that work was the idea that maintenance was no longer a reactive or merely preventive activity—it was becoming connected, predictive, and more intelligent.

At the core of this shift was the integration of Enterprise Asset Management (EAM) platforms with Asset Performance Management (APM) tools. These technologies, coupled with sensorization and early applications of machine learning, offered unprecedented visibility into asset condition, enabling risk-informed decision-making and optimized maintenance scheduling. The book outlined a transition from traditional maintenance hierarchies toward data-driven ecosystems, where failure prediction, remote diagnostics, and lifecycle strategies could converge.

However, by 2022, several structural limitations were still evident:

- Fragmentation of digital tools: Many implementations remained siloed, unable to communicate across systems or scales.
  - Low semantic interoperability: Standards existed but were inconsistently applied or too generic to bridge operational layers.
  - Immature organizational alignment: Most digital initiatives were still IT-led, with little operational ownership or strategic governance.
  - Unclear governance of AI and data ethics, especially in regulated environments.
  - Pilot fatigue: Many initiatives stalled at proof-of-concept stage due to lack of scalability or integration planning.

These gaps highlighted the need for a more integrated, scalable, and sustainable approach to digital transformation in maintenance—one that is now taking shape through global developments in technology, standards, and industrial policy.

## 4. Trends 2023–2025: What Has Evolved

Since 2022, several trends have gained momentum, reshaping the digital maintenance landscape and addressing some of the limitations previously observed.

### 4.1 Maturity of Digital Twin Deployment

Digital twins, once confined to high-value, isolated assets, are now becoming part of scaled infrastructure strategies. The emergence of standards like the Asset Administration Shell (Platform Industrie 4.0, 2019) and taxonomy efforts by the Digital Twin Consortium (2022) have enabled a more structured approach to modeling, simulating, and orchestrating asset behavior across their lifecycle. These twins now link real-time data with operational logic, enabling what-if simulations, condition-based planning, and automated decision triggers.

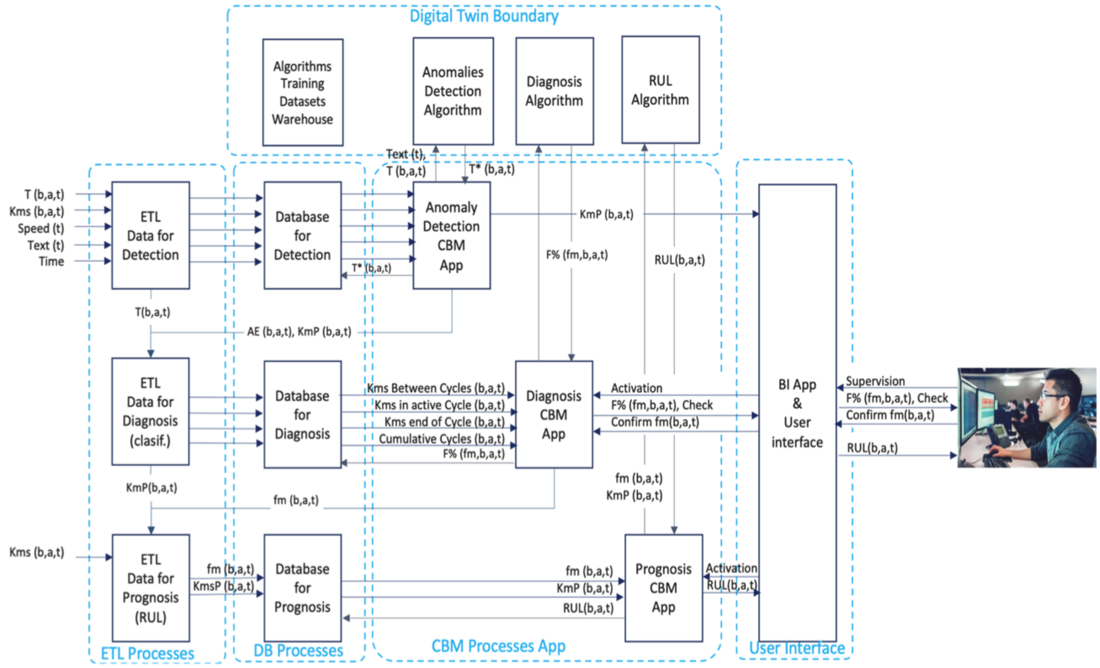


**Figure 1.** "Digital twins in condition-based maintenance apps: (taken from Crespo et al. 2023)

## 4.2 AI Governance and Ethical Deployment

The growing use of AI in maintenance—particularly for failure prediction, anomaly detection, and resource optimization—has led to an urgent need for governance. The publication of ISO/IEC 42001 (2023), the first standard for AI management systems, marks a significant step toward ensuring transparency, accountability, and trust in algorithmic maintenance systems. Ethical concerns such as model bias, explainability, and workforce displacement are now on the radar of both regulators and industry bodies (OECD, 2021).

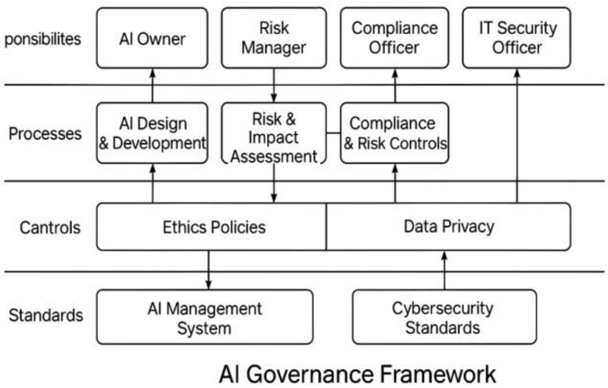


**Figure 2.** Adapted governance cycle inspired by ISO/IEC 42001:2023 for AI systems in maintenance.

### 4.3 Real-Time Diagnostics and Cloud-to-Edge Integration

Recent studies confirm (Kelly, 2025) how edge computing is being able to transform real-time data processing by bringing computation closer to data sources, thus minimizing latency and enabling immediate response in critical sectors such as healthcare, industrial automation, and smart cities. Its decentralized architecture supports localized analytics, reducing reliance on centralized cloud infrastructure and improving both efficiency and resilience.

Edge computing also offers a scalable solution to manage the surge of data from IoT devices, overcoming the bandwidth and latency limitations of traditional cloud models. Additionally, edge systems strengthen data security and privacy by processing sensitive data locally. This is particularly importance in sectors like healthcare and finance.

Beyond operational benefits, the study highlights edge computing's role in fostering innovation and economic growth. It enables applications such as real-time traffic optimization and predictive maintenance, reinforcing its value as a foundational technology in digital transformation.

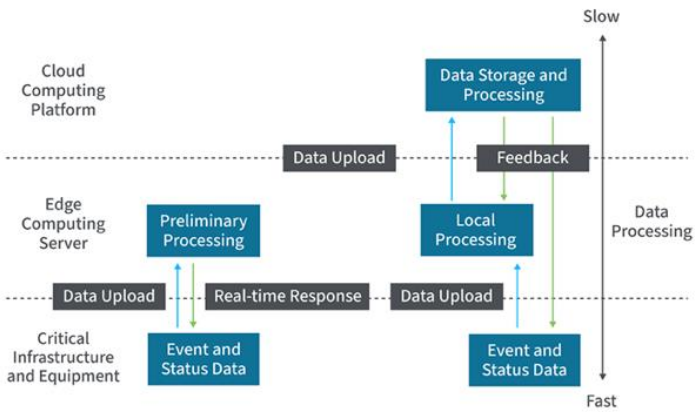


Figure 3. The Edge and Cloud Computing Relationship (Kurduban, 2024)

The convergence of 5G connectivity, edge computing, and industrial IoT platforms has enabled diagnostics at scale. Assets can now be monitored in near real time, even in remote environments, allowing for autonomous fault detection and rapid response coordination. Cloud-to-edge architectures are becoming standard, with distributed intelligence enhancing system resilience and reducing latency.

### 4.4 Consolidation of EAM–APM–AIP Architecture

Perhaps the most strategic trend is the consolidation of Enterprise Asset Management (EAM), Asset Performance Management (APM), and Asset Investment Planning (AIP) capabilities into integrated platforms. Major software providers—such as SAP (SAP, 2023), IBM (IBM, 2023), Siemens (Siemens Energy, 2022), and GE Digital (2021)—have evolved their product ecosystems to support the full asset value chain.

- EAM continues to support operational and regulatory maintenance processes (e.g., work orders, asset hierarchies, spare parts),
- APM delivers condition analytics, reliability models, and risk-informed planning,

- AIP introduces multi-year investment optimization based on cost, risk, and performance trade-offs (Copperleaf Technologies, 2021).

This architectural integration fosters closed-loop control: from sensor data to risk-based maintenance, and from performance gaps to capital reallocation. It also enables scenario-based planning and alignment with ESG and resilience objectives.

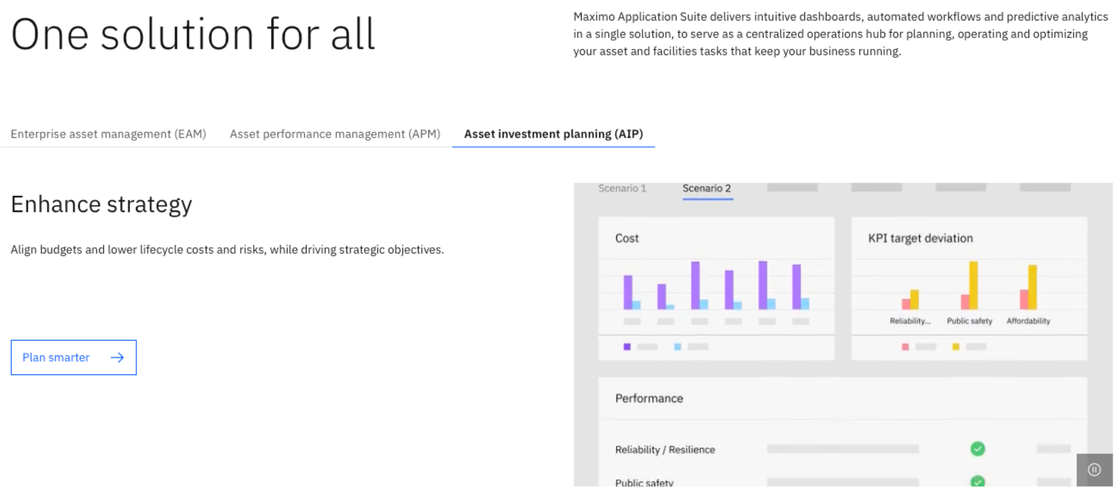


**Figure 4**. Maximo Application Suite offering "Features": AEM, APM & AIP. Taken 22.05.2025 from https://www.ibm.com/products/maximo

### 4.5 Data Sovereignty and Secure Interoperability

As maintenance ecosystems extend beyond single organizations, data sovereignty—the ability of data owners to control access, use, and governance—has become a critical requirement in digital infrastructure. Traditional centralized models fall short when handling multi-stakeholder operations that demand federated trust, such as in rail, aviation, and energy maintenance networks (Cavoukian & Naudts, 2023).

Initiatives like Gaia-X and the International Data Spaces Association (IDSA) have responded by establishing federated data-sharing frameworks that ensure technical interoperability, enforceable policies, and sovereign control over information flows. Gaia-X's 2023 Compliance Document formalizes the governance conditions under which services and platforms may participate in sovereign ecosystems, including identity verification, access control, and secure data flows (Gaia-X Association, 2023).

In parallel, the IDS Dataspace Protocol v2024-1 introduces detailed guidance for semantic compatibility, trust provisioning, and policy enforcement across distributed data infrastructures. These frameworks emphasize the importance of data usage control, whereby data providers can set and enforce conditions even after data has left their immediate domain (IDSA, 2024).

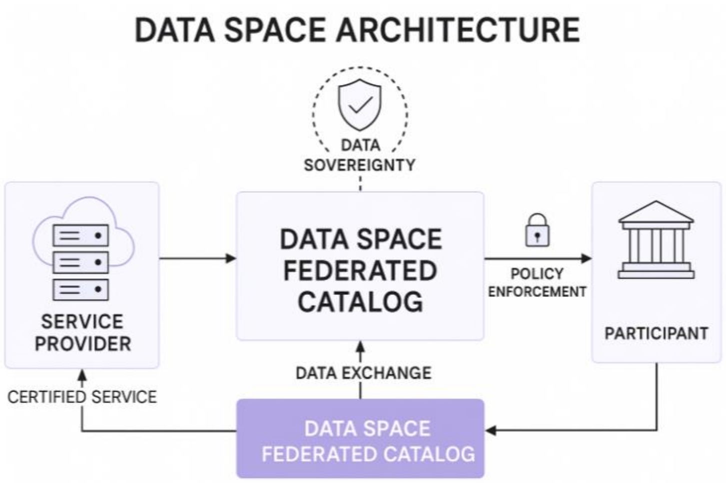


**Figure 5**. Federated Data Space Architecture for Sovereign and Interoperable Maintenance Ecosystems

Diagram in Figure 5, shows how data sovereignty and interoperability are supported through a federated, standards-based model. This makes data sharing in maintenance both secure and interoperable. Elements of this model are:

| **Benefit** | **Description** |
|---|---|
| **Sovereign Control** | Asset owners retain legal & technical control over how their data is used |
| **Secure Federation** | Credentials, compliance labels, and real-time policy checking enable trust in shared ecosystems |
| **Semantic Consistency** | Use of ontologies and shared schemas ensures that data retains meaning when exchanged |
| **Scalable Architecture** | The federation allows expansion without centralized bottlenecks |

An illustrative initiative in this domain is Manufacturing-X, developed under the auspices of Platform Industrie 4.0, which places data sovereignty and interoperability at the core of future industrial architectures. Through its reference use cases—many of which address digital maintenance scenarios—Manufacturing-X showcases the increasing implementation of decentralized and federated data infrastructures to support real-world applications (Platform Industrie 4.0, 2024). These developments reflect a broader shift toward architectures that enable controlled, cross-enterprise data exchange in complex industrial ecosystems.

In parallel, international institutions such as the World Economic Forum have emphasized that embedding trust and sovereignty into digital infrastructure is a prerequisite for viable public-private data collaboration and long-term regulatory alignment (World Economic Forum, 2024). As industrial organizations progressively depend on shared maintenance platforms, the convergence of technical standards, semantic consistency, and enforceable governance frameworks becomes essential for achieving reliable and scalable interoperability.

A critical enabler of this interoperability is the advancement of shared ontologies and metadata schemas that enable the semantic interpretation of data across heterogeneous systems. For instance, Oliveira et al. (2024) introduce an ontology-based framework to support legal and semantic interoperability within international data spaces, addressing a key gap between operational needs and regulatory requirements. Similarly, Hodkiewicz et al. (2022) argue that semantic interoperability is foundational for effective cross-organizational data integration. Their interesting work maps ISO 14224 maintenance data structures onto industrial knowledge graphs, enabling automated reasoning, improved data consistency, and decision support across digital twins and asset management platforms. This aligns with the goals of the Gaia-X and IDS initiatives by providing a structured and machine-readable foundation for federated sovereign data exchange.

In domains characterized by complex multi-stakeholder coordination—such as rail, aviation, and energy networks—these distributed and policy-enforced architectures provide resilience, maintain compliance with regulatory frameworks, and enable real-time, cross-organizational decision-making.

In conclusion, the architectural integration proposed by Gaia-X and IDS, underpinned by continuous governance, certification mechanisms, and semantic harmonization, constitutes a foundational step toward transforming maintenance ecosystems into secure, interoperable, and sovereign digital platforms capable of supporting scalable collaboration and innovation.

## 4.5 Evolving Standards and Regulatory Alignment

As digital maintenance systems grow more autonomous, connected, and data-driven, the regulatory and standardization landscape is undergoing a necessary evolution. This transformation is not only about creating new standards, but also about aligning existing frameworks to ensure semantic coherence, governance compatibility, and scalability.

Recent years have seen the publication of new normative references designed to address emerging needs in artificial intelligence, cybersecurity, and interoperability:

- ISO/IEC 42001 (2023) introduces the first formal requirements for AI management systems, covering algorithmic transparency, bias mitigation, and auditability in critical domains such as predictive maintenance and anomaly detection.
- IEC 62443, now in its 2024 revised edition, expands its cybersecurity controls to cover edge computing nodes, OT/IT convergence, and supply chain vulnerabilities, making it directly applicable to industrial maintenance platforms operating in federated or remote architectures.

- IEC 62264 (Edition 5, 2023) strengthens the enterprise–control system integration model, incorporating digital thread principles and updated mapping to ISA-95 Level 3/4 boundaries, which are essential for aligning condition monitoring systems with enterprise asset management (EAM) and asset investment planning (AIP) platforms.

Simultaneously, implementation guidance for established standards is being refined:

- New technical specifications and application guides for ISO 55001 focus on the integration of digital workflows and real-time asset data within asset management systems.
- The ISO 14224 community is extending the standard to include machine-readable schemas and compatibility with knowledge graph–based infrastructures, in line with initiatives like Asset Administration Shells (AAS) and IDSA-compliant data spaces.

The result is a gradual but necessary shift from framework proliferation to harmonization—a trend driven by the need to reduce fragmentation, improve interoperability, and support scalable implementations across sectors. This evolution supports organizations in deploying digital maintenance strategies that are not only technologically advanced but also regulatory-compliant, certifiable, and auditable.

By 2025, these developments are converging toward a layered ecosystem of standards where governance (ISO/IEC 42001), security (IEC 62443), semantic data exchange (ISO 14224 extensions), and operational integration (IEC 62264) can interoperate to support secure, intelligent, and efficient maintenance operations across increasingly complex and distributed infrastructures.

## 5. Persisting Barriers and Structural Misalignments

Despite the rapid development of technological enablers and the proliferation of digital frameworks, significant challenges continue to constrain the full adoption of intelligent maintenance practices. Chief among these is the fragmentation of asset data across siloed systems, a legacy issue that resists harmonization despite the maturity of standards such as ISO 14224 and IEC 81346. In many organizations, enterprise asset management (EAM) platforms operate in isolation from condition monitoring tools, and even more so from financial planning environments. This disconnect undermines the ability to transition from predictive alerts to risk-informed investment decisions.

Another persistent limitation lies in the misalignment between digital ambitions and organizational readiness. Digital maturity assessments consistently reveal gaps in data governance, workforce capabilities, and change-management infrastructure. While cloud-native platforms, edge architectures, and AI-based diagnostics have matured, their integration into operational and decision-making processes remains uneven. Furthermore, cybersecurity concerns and unclear data ownership protocols—especially in multi-stakeholder environments such as rail and energy—compound the hesitation to move towards open, interoperable ecosystems. Initiatives such as Gaia-X and the International Data Spaces Association (IDSA) have responded to these challenges by proposing federated, sovereign data infrastructures, but adoption remains incipient.

## 6. Strategic Enablers and the Need for Institutional Models

Overcoming these limitations will require not only technological investment but also the reconfiguration of maintenance governance. A key enabler lies in adopting layered, standards-based architectures that provide a stable foundation for integration. Reference models such as RAMI 4.0, IIRA, and the Asset Administration Shell (AAS) now converge to offer a coherent structuring logic for intelligent asset systems. Their utility extends beyond interoperability: they anchor governance and foster cross-domain visibility.

The convergence of Asset Performance Management (APM) and Asset Investment Planning (AIP) also deserves special attention. When real-time health data is meaningfully linked to lifecycle cost projections, organizations can optimize asset strategies under uncertainty. This synergy moves maintenance from a purely operational function to a lever of financial performance and risk management. Such integration is increasingly facilitated by software platforms that natively support the AEM–APM–AIP logic—observable in market leaders like IBM, SAP, GE, and Copperleaf—suggesting an industry-wide shift toward architectural coherence.

Additionally, the expansion of open, standards-based platforms offers an alternative to proprietary vendor ecosystems. The Open Industry 4.0 Alliance and Digital Twin Consortium have promoted blueprints that emphasize semantic consistency, federated data access, and compliance-by-design. These ecosystems provide the scaffolding for shared maintenance services and cross-enterprise intelligence, particularly in industrial clusters and transportation corridors.

However, none of these technological trajectories will succeed without parallel investment in human capabilities. The upskilling of technicians, engineers, and analysts to work with data-driven tools is essential. Human-centric automation—where diagnostics augment rather than replace expertise—must guide implementation. Leading organizations increasingly embed change agents, digital champions, and cross-functional task forces to support this transition.

## 7. Toward an Intelligent Maintenance Ecosystem

Looking ahead to 2030, the horizon for maintenance is not merely digital—it is intelligent, adaptive, and institutionalized. This vision demands a rethinking of asset management as a socio-technical ecosystem, where data is not just an operational artifact but a strategic asset. Holistic frameworks are needed to unify telemetry, simulation, financial planning, and regulatory compliance. These frameworks will be embedded in platforms that enable collaborative governance, traceability, and transparency.

Furthermore, data valorization will become a defining feature of the next phase. Maintenance data will be increasingly monetized or leveraged beyond its original operational context—whether to optimize supply chains, participate in data marketplaces, or train large-scale AI models. Semantic standards and secure data spaces will provide the conditions for this exchange, enabling maintenance organizations to capture value from their informational assets.

Ultimately, this evolution requires institutional change. The establishment of Digital Maintenance Centers of Excellence (DM-CoEs), cross-industry consortia, and embedded research and development functions will become critical. These structures will ensure that learning is codified, best practices are disseminated, and standards remain aligned with emerging technological and regulatory landscapes.

## 8. Conclusion: Redefining Maintenance in a Digital Age

This chapter has offered a structured overview of the ongoing digital transformation in maintenance, following a logical path from the foundations established in 2022 to the most recent developments shaping the period 2023–2025. At the time of the previous book, the focus was on the convergence of predictive maintenance with emerging digital tools and the early stages of integration across EAM, APM, and AIP platforms. That vision is now materializing in many industries, with increasing deployment of digital twins, cloud-to-edge architectures, and platform-based approaches that embed intelligence into maintenance ecosystems.However, the progress made so far also highlights what remains unresolved. The consolidation of frameworks, the harmonization of standards, and the operational integration of asset data into strategic planning still face structural, organizational, and technological barriers. The promise of data-driven maintenance is no longer questioned—but the capacity to scale, govern, and extract value from that data across stakeholders is still a work in progress.

Throughout the chapter, we have emphasized that digital maintenance is not a collection of technologies, but a new paradigm—one that redefines how maintenance is understood, organized, and valued. Moving forward, the emphasis must shift from fragmented experimentation to systemic alignment. This will require not only tools and architectures, but new competencies, governance structures, and cross-functional strategies.

The road ahead points toward intelligent, collaborative, and sovereign maintenance environments. Maintenance will no longer be reactive or even merely predictive—it will be strategic, contextual, and embedded into the core of operational and financial decision-making. This chapter sets the tone for the rest of this volume, where these themes will be explored in depth through standards, technologies, applications, and emerging strategies.

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