APRIL 2026

WHITE PAPER

IoT Devices and Platforms in Healthcare Logistics

Enabling Predictive, Secure, and End-to-End Supply Chain Visibility

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ABSTRACT

The pharmaceutical supply chain is undergoing a structural transformation driven by advanced biologics, cell and gene therapies, vaccines, and personalised medicine. These therapies require strict environmental control, regulatory compliance, and seamless global coordination. Yet, despite significant technological progress, most healthcare logistics ecosystems remain reactive, fragmented, and partially digitised.

This White Paper presents the findings of the Pharma.Aero project "IoT Devices and Platforms in Healthcare Logistics." Through desk research, industry surveys, expert interviews and trainings the project assesses the maturity of next-generation Internet of Things (IoT) technologies and their ability to enable end-to-end visibility, predictive analytics, and proactive intervention across multimodal pharmaceutical supply chains.

The results confirm that IoT technologies, when combined with artificial intelligence (AI), secure connectivity, and structured training, can transform conventional control towers into predictive command centres. However, barriers remain: inconsistent global connectivity, limited data standardisation, cybersecurity concerns, regulatory fragmentation, and insufficient digital skills.

By uniting pharmaceutical manufacturers, airlines, freight forwarders, technology providers, and airports, Pharma.Aero provides a neutral, cross-industry platform to address these challenges collaboratively. The project demonstrates that the future of pharmaceutical logistics lies not merely in tracking products but in unlocking data-driven intelligence that safeguards patients, protects product value, and ensures global healthcare resilience.

INTRODUCTION

Pharmaceutical logistics has never been more complex. The rise of temperature-sensitive biologics, mRNA vaccines, gene therapies, and personalised medicines has expanded distribution requirements beyond traditional cold chain management. Products now move through intricate, multimodal routes under strict regulatory oversight and increasing public scrutiny.

Regulatory frameworks such as Good Distribution Practice (GDP), aviation safety requirements, and global compliance standards demand documented proof of environmental control, data integrity, and traceability. Meanwhile, geopolitical instability, infrastructure limitations, and sustainability pressures intensify operational risks.

Historically, monitoring relied heavily on passive data loggers and Radio-Frequency Identification (RFID) systems. While valuable, these technologies often provide post-event visibility rather than real-time intelligence. Today, next-generation IoT devices, equipped with multi-sensor capabilities, global connectivity, and cloud-based platforms, offer the potential to transform visibility into foresight.

Building upon its previous "Innovation in Motion" project, Pharma.Aero launched the "IoT Devices and Platforms in Healthcare Logistics" project to assess technological readiness, identify industry needs, and support digital maturity across the life sciences ecosystem.

As a global cross-industry collaboration platform, Pharma.Aero brings together manufacturers, logistics providers, airlines, airports, and solution providers to jointly advance innovation in healthcare transportation. This White Paper captures the collective insights and strategic direction emerging from this collaboration.

OBJECTIVES

The "IoT Devices and Platforms in Healthcare Logistics" project was designed to assess the maturity, applicability, and strategic value of next-generation IoT technologies across the pharmaceutical supply chain. Building on prior industry research and cross-sector collaboration initiatives led by Pharma.Aero, the project focused on three core work packages that move sequentially from diagnosis to practical validation, to capability development.

The overarching ambition was not to evaluate technology but to determine how IoT devices and digital platforms can enable end-to-end visibility, predictive risk management, regulatory compliance, and data-driven decision-making in an increasingly complex healthcare logistics environment.

Work Package 01

Diagnosis and Needs Assessment

The first objective was to establish a clear, evidence-based understanding of the current state of IoT adoption in pharmaceutical logistics and to identify both cross-functional and stakeholder-specific gaps.

This diagnostic phase created a structured baseline for understanding maturity levels, investment readiness, and strategic alignment across the ecosystem.

Work Package 02

Use Case Identification and Validation

The second objective focused on translating theoretical potential into operational reality by documenting real-world use cases from Pharma.Aero members.

By showcasing concrete implementations, this work package validated that IoT technologies deliver tangible value when properly integrated into operational workflows.

These use cases also revealed the conditions required for success: cross-functional coordination, platform interoperability, data reliability, and clearly defined governance structures.

Work Package 03

Awareness Raising and Capability Development

The third objective addressed a critical insight from the needs assessment: technology alone does not create transformation, capability does.

Despite growing IoT deployment, most stakeholders continue to use data reactively. To unlock predictive and prescriptive potential, organisations require structured upskilling and change management.

The objective of this phase was to ensure that IoT adoption evolves from a device-centric implementation to a data-centric transformation, empowering stakeholders to convert visibility into intelligence and intelligence into action.

METHODOLOGY

The project followed a structured, multi-layered methodology:

[01]

Desk Research

A comprehensive review of:

- IoT sensor technologies
- Connectivity protocols
- AI and machine learning models
- Regulatory requirements
- Blockchain and cybersecurity frameworks

[02]

Industry Survey

Stakeholders from pharmaceutical companies, airlines, & freight forwarders provided structured feedback on:

- Current IoT usage maturity
- Operational pain points
- Connectivity barriers
- AI confidence levels
- Data quality challenges

[03]

Expert Interviews

In-depth interviews were conducted with representatives from Etihad Cargo, JAS Worldwide and MSD to contextualise survey results.

[04]

Governance and Peer Review

The project benefited from structured oversight by board members, project leads from Pharma.Aero membership and a panel of associate partners, ensuring balanced, cross-sector representation.

[05]

Capability Development in Practice: Structured Executive Training

To operationalise digital maturity, Pharma.Aero facilitated three targeted executive training sessions addressing the strategic, technical, and organisational dimensions of IoT and AI integration:

- Fundamentals of Artificial Intelligence in Pharmaceutical Logistics (trainer: Hunter Ferrell, Aspen Telematix)
- Strategic use of IoT Data (trainer: Enrique CondeGil, external project expert)
- Operational Change & Change Management (trainer: Enrique CondeGil, external project expert)

RESULTS

The results of the "IoT Devices and Platforms in Healthcare Logistics" project reveal a sector in transition. While IoT technologies are widely recognised as critical enablers of visibility, compliance, and operational excellence, their full potential remains underleveraged across the pharmaceutical logistics ecosystem.

Through structured research, stakeholder surveys, and expert interviews, Pharma.Aero identified clear patterns: strong awareness, moderate adoption, fragmented implementation, and limited strategic integration. The following sections introduce the key findings in a structured and progressive manner, starting from current maturity levels, moving through technical and operational considerations, and concluding with stakeholder-specific insights and demonstrated impact.

1. The Current State of IoT Adoption

Digital transformation in pharmaceutical logistics is no longer optional but a structural necessity. Increasing product sensitivity, rising regulatory expectations, and global distribution complexity demand real-time insight into environmental conditions, shipment milestones, and risk exposure. IoT devices have emerged as one of the most promising enablers of this transformation.

However, the assessment conducted within this project shows that while IoT technologies are broadly deployed, their use remains predominantly operational and reactive rather than strategic and predictive.

Across pharmaceutical companies, airlines, and freight forwarders, IoT solutions are most used for:

- Temperature monitoring
- Location tracking
- Alert-based deviation management
- Basic compliance documentation

In most cases, IoT systems are implemented to "detect and respond" rather than to "predict and prevent."

The project training session on the Strategic Use of IoT Data further validated this maturity gap. While device deployment is expanding, structured analytics progression remains limited.

Participants explored a **four-stage** analytics framework:

Descriptive – *What happened?*

Diagnostic – *Why did it happen?*

Predictive – *What is likely to happen?*

Prescriptive – *What action should be taken?*

Most organisations currently operate at the descriptive level, with limited institutionalisation of predictive modelling or prescriptive optimisation.

This confirms that visibility alone does not create competitive advantage. Value emerges when IoT data is embedded into structured decision architectures aligned with operational and financial objectives.

Key Observations

Partial Visibility Rather Than Full Traceability

Although many stakeholders report moderate to high levels of visibility, none of the surveyed groups have achieved fully integrated, end-to-end, piece-level traceability across all supply chain nodes. Visibility gaps remain particularly pronounced during multimodal transitions and handovers.

Reactive Monitoring Culture

IoT data is typically accessed after alerts are triggered. Few organisations have embedded IoT analytics into proactive lane risk assessments, continuous improvement cycles, or predictive route optimisation models.

Connectivity as a Structural Constraint

Inconsistent global connectivity, particularly in remote regions, airport tarmac environments, and during ocean freight, continues to limit real-time data reliability. Even when devices are technically capable, infrastructure constraints reduce practical effectiveness.

Fragmented System Landscape

Many organisations operate multiple platforms from different vendors without full interoperability. This fragmentation results in parallel dashboards, duplicated data storage, and inefficiencies in decision-making.

These findings indicate that the industry is at an intermediate maturity stage: technology is available and deployed, but strategic integration is still evolving.

2. Operational and Technical Considerations

Successful IoT deployment in pharmaceutical logistics requires more than selecting a sensor. It demands a holistic evaluation of product characteristics, regulatory constraints, connectivity environments, sustainability targets, and operational workflows.

This project identified several critical technical and operational dimensions that influence implementation success.

- Sensor Strategy and Configuration
- Connectivity Architecture
- Battery and Aviation Compliance
- Operational Model Selection

3. Advanced Analytics and AI Integration

While IoT devices generate vast amounts of data, raw data alone does not create value. The strategic advantage lies in the ability to transform sensor outputs into actionable intelligence.

The project identified a significant maturity gap between data generation and data exploitation.

FROM VISIBILITY TO INTELLIGENCE

Most stakeholders currently operate at the descriptive level of analytics: monitoring what is happening in real time. However, the real opportunity lies in advancing toward predictive and prescriptive analytics.

The analytical progression can be summarised as follows:

- **Descriptive Analytics** – *What happened?*
- **Diagnostic Analytics** – *Why did it happen?*
- **Predictive Analytics** – *What is likely to happen?*
- **Prescriptive Analytics** – *What action should be taken?*

While awareness of predictive capabilities is growing, practical implementation remains limited.

AI AND MACHINE LEARNING POTENTIAL

Advanced techniques including anomaly detection models, supervised classification, recurrent neural networks, and multivariate deep learning enable:

- Early detection of temperature drift
- Lane risk profiling
- Shipment prioritisation
- Automated intervention recommendations

However, successful AI deployment requires foundational prerequisites:

- High-quality and labelled datasets
- Consistent data capture without gaps
- Secure, controlled data environments
- Skilled personnel capable of model interpretation

Survey responses revealed cautious optimism: stakeholders recognise AI's potential but remain concerned about data quality, integration complexity, unclear ROI, and governance risks. Pharma.Aero's role in facilitating training and cross-industry dialogue is critical to accelerating responsible AI maturity.

CAPABILITY VALIDATION: FROM MONITORING TO PREDICTION

Insights generated during the project's executive training on Artificial Intelligence in Pharmaceutical Logistics confirmed a structural industry gap: while AI tools are widely discussed, their effective deployment is constrained primarily by data architecture maturity rather than algorithm availability.

The session emphasised a strategic shift from static threshold monitoring ("in spec / out of spec") toward probabilistic, risk-based management models capable of:

- Predictive temperature excursion forecasting
- Lane-, carrier-, and season-aware risk modelling
- Dynamic ETA recalibration
- Intelligent alert prioritisation to reduce signal noise

A critical conclusion emerged: **AI does not compensate for weak data infrastructure. It amplifies it.**

Participants consistently highlighted that explainability, auditability, and human oversight remain mandatory in GDP/GxP-regulated environments. AI must support, not replace, compliance governance and quality release decisions.

This reinforces the project's broader finding: predictive supply chains require secure, high-resolution IoT data ecosystems before advanced AI models can create measurable value.

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4. Security and Compliance Imperatives

As IoT adoption increases, so does the cyber-physical attack surface of pharmaceutical supply chains. Connected devices introduce vulnerabilities that extend beyond temperature deviations into digital security, data integrity, and aviation safety domains.

The project identified three major risk categories: device security, data integrity, and signal reliability.

CYBER-PHYSICAL THREAT LANDSCAPE

Potential risks include:

- Unauthorised signal interception
- RFID or BLE cloning and spoofing
- Device hijacking or remote manipulation
- Deliberate signal jamming
- False data injection

Such threats carry operational, financial, and reputational consequences, particularly in high-value or public health contexts.

DATA INTEGRITY AND REGULATORY COMPLIANCE

Regulatory frameworks require tamper-proof, auditable temperature records. Connectivity gaps, corrupted logs, or unverifiable data trails can result in:

- Product quarantine or destruction
- Compliance violations
- Audit findings
- Reputational damage

Mitigation strategies must be implemented to effectively address and manage the identified risks.

DEVICE SAFETY IN AIR CARGO

Lithium battery safety remains a core aviation concern. Manufacturers must integrate:

- Certified battery testing
- Over-discharge protection circuitry
- Crush-resistant enclosures
- Regulatory labelling compliance

Security must be embedded into design, procurement, and operational processes.

5. Stakeholder-Specific Insights

While cross-functional challenges exist, each stakeholder group faces distinct maturity gaps and strategic considerations.

PHARMACEUTICAL COMPANIES

Pharma companies demonstrate relatively higher visibility maturity but face challenges in:

- Certified battery testing
- Over-discharge protection circuitry
- Crush-resistant enclosures
- Regulatory labelling compliance

Strategic decisions are often constrained not by technology availability but by governance complexity and business case clarity.

AIRLINES

Airlines report the lowest visibility maturity, particularly at piece-level tracking after shipment breakdown.

Key challenges include:

- Fragmented tracking across airport environments
- Regulatory diversity across jurisdictions
- Infrastructure gaps
- Complexity of transitioning from paper-based workflows

However, airlines also demonstrate strong interest in API (Application Programming Interface) integration and milestone-based transparency models.

FREIGHT FORWARDERS

Freight forwarders operate in highly fragmented, multi-vendor ecosystems.

Primary concerns include:

- Data ownership risks
- Vendor dependency
- Connectivity gaps
- Limited predictive integration

There is growing demand for neutral platforms and interoperable systems that reduce fragmentation and enhance collaboration.

Across all stakeholders, common needs emerge:

- Improved data quality and standardisation
- Stronger cybersecurity governance
- API-based interoperability
- Digital skill development
- Change management support

These findings reinforce Pharma.Aero's unique value: providing a neutral, cross-industry environment where stakeholders can collectively address shared structural challenges while respecting differentiated operational realities.

ORGANISATIONAL READINESS AND CHANGE LEADERSHIP

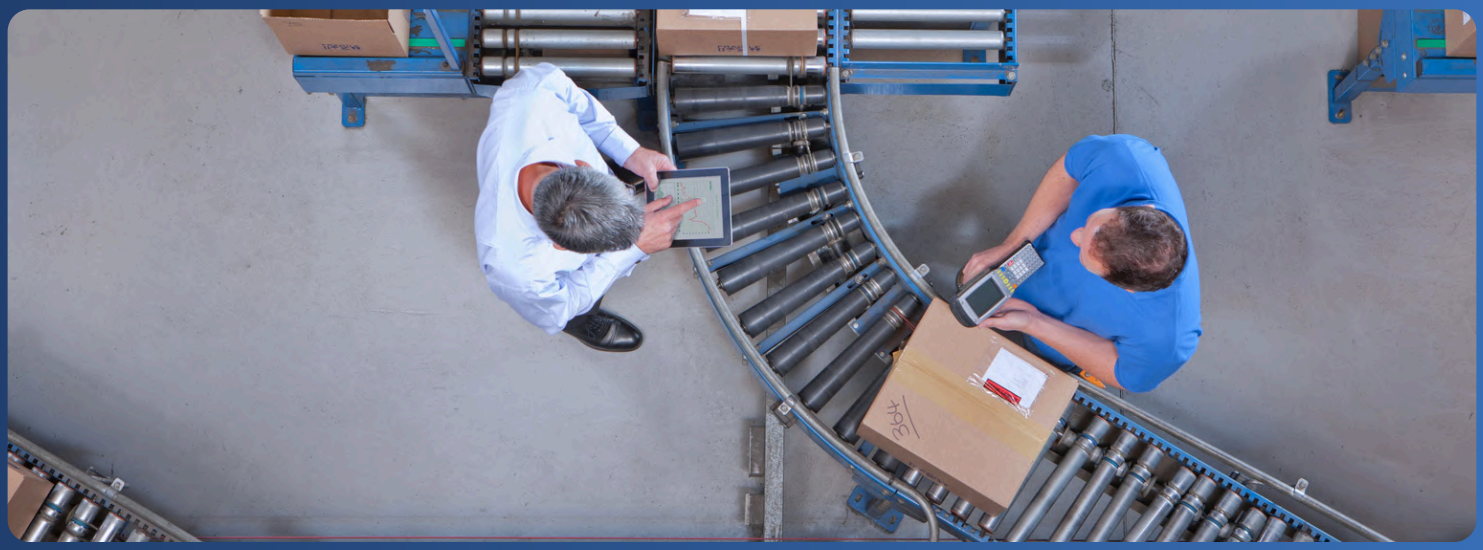
Training on Operational Change and AI-Enabled Leadership revealed that technological deployment is rarely the primary barrier to transformation. Instead, challenges stem from process standardisation gaps, automation readiness, and cognitive biases in decision-making.

Discussions addressed the distinction between Robotic Process Automation (RPA) and Intelligent Process Automation (IPA), emphasising that automation success depends on:

- Clearly defined and standardised workflows
- Cross-functional orchestration
- Leadership capable of managing uncertainty
- Critical thinking when applying AI-generated recommendations

The "Centaur" concept (humans leveraging AI as cognitive amplifiers) resonated strongly. AI tools are most effective when paired with structured problem decomposition, governance clarity, and human accountability.

These findings reinforce a central project insight: predictive healthcare logistics is as much an organisational transformation as a technological one.



CONCLUSIONS

The pharmaceutical industry stands at a digital inflection point.
IoT technologies are no longer experimental; they are essential. Yet maturity gaps persist in connectivity, interoperability, AI integration, and workforce capability.

The project demonstrates that:

- IoT is foundational for modern pharma logistics
- Analytics transforms visibility into intelligence
- Security and compliance must be integrated from design stage
- Training is critical to unlock value
- Cross-industry collaboration accelerates scalable adoption

Pharma.Aero plays a pivotal role in orchestrating this transformation. By convening stakeholders across the value chain, conducting neutral research, and delivering targeted training, Pharma.Aero enables the shift from fragmented monitoring to predictive command centres.

"During a critical vaccine shipment to India, an IoT alert indicated that temperatures were approaching a deviation threshold while the sample was being transported in a non-temperature-controlled vehicle. Thanks to real-time visibility, the team intervened immediately, ensuring the product was placed under proper refrigeration. This proactive action enabled quality release without delay and safeguarded the timely delivery of millions of vaccine doses."

Ruud van der Geer,
Global Deliver Strategy, MSD

"The global distribution of our COVID-19 vaccine required ultra-low temperature control at unprecedented scale. By implementing real-time IoT temperature and location monitoring, we significantly reduced product rejection rates, enabled data-driven re-icing decisions, accelerated shipment quality release, and enhanced overall reliability. Beyond operational improvements, this approach created a clear competitive advantage and strengthened confidence across the supply chain."

Can Pekerbas,
Transportation Director, Pfizer

ACKNOWLEDGEMENTS

Pharma.Aero extends its sincere appreciation to all members, project leads, subject matter expert Enrique CondeGil, and associate partners who contributed their expertise and insights to this project.

Special recognition is given to representatives from MSD, Pfizer, Etihad Cargo and JAS Worldwide for sharing operational knowledge and real-world experiences.

This White Paper reflects a collective industry effort to advance patient-centric, resilient, and digitally empowered pharmaceutical supply chains.

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