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Case for Enabling Blockchain Adoption in Aviation MRO via MBSE-Driven Operational Analysis

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ENABLING BLOCKCHAIN ADOPTION IN AVIATION MRO VIA MBSE-DRIVEN OPERATIONAL ANALYSIS

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Abstract. The aviation industry struggles with data silos, poor traceability of parts and procedures, and manual compliance efforts resulting in inefficiencies, expensive delays, and regulatory challenges. These challenges heap on in a multi-stakeholder environment involving airlines, lessors, OEMs, MROs and regulators like FAA, EASA or DGCA, where data integrity and auditability need to be flawless.

Traditional process-improvement approaches fall short in navigating such distributed, tightly regulated environments. What is needed is a structured, operational view of how various actors interact, what capabilities exist, and where trust or coordination breaks down. Model-Based Systems Engineering (MBSE) emerges as the only viable approach to model this operational fabric with the depth and rigor required for transformation.

Multiple studies and industry proposals highlight blockchain's potential in aviation—particularly for parts traceability, maintenance log immutability, and secure, shared ledgers among stakeholders. Yet despite years of research, real-world adoption remains scarce. Why? Because blockchain's implementation isn't a technological problem, it's a systems integration challenge. The operational complexity of the MRO ecosystem, characterized by fragmented workflows, legacy systems, and overlapping regulatory jurisdictions, makes teams hesitant to commit. Traditional systems engineering methods often fall short here; they lack traceability across stakeholder concerns, provide limited capability for scenario-based validation, and struggle with modeling socio-technical interfaces like contracts and trust. Only Model-Based Systems Engineering (MBSE), with its structured modeling, simulation-ready architecture, and stakeholder-aligned viewpoints, can tackle this class of integration problem with the required precision and confidence.

This paper applies MBSE principles to bridge the blockchain integration gap by systematically modeling MRO operations and potential blockchain roles using the Capella tool and the Arcadia methodology. By developing an operational architecture that includes stakeholder entities, operational capabilities, and inter-entity activities, we explore and interpret critical integration points such as maintenance log immutability, parts traceability, and smart contract driven work order automation. The operational models demonstrate how MBSE aids in validating blockchain applicability, revealing both opportunities and boundaries of its implementation in regulated aviation environments.

The work lays the foundation for a consortium-based architectural approach and outlines a path toward future model validation, governance structuring, and digital thread integration. This study shows that adopting emerging technologies in aviation requires not just engineering vision, but systems-level operational clarity - exactly what MBSE provides.

Keywords. Model-Based Systems Engineering (MBSE), Blockchain, Aviation MRO, Operational Architecture, Capella, Arcadia, Digital Thread, Parts Traceability, Maintenance Records, Systems Integration, Consortium Architecture

Introduction

Aviation Maintenance, Repair, and Overhaul (MRO) operations are at the lesser known keys of aircraft safety, reliability, and lifecycle cost efficiency. Despite being super critical, these operations face challenges from fragmented workflows, limited digitization, and a shocking lack of end-to-end traceability. The industry spends over $50 billion annually on aircraft spare parts (PwC, 2019), yet tracking and certifying these parts is still a mostly manual, paper-driven effort. This lack of real-time, reliable visibility not only inflates operational costs but also introduces risks that compromise airworthiness and regulatory compliance, not mentioning the fraudulence that keeps the MROs do all-nighters (Randell, 2025).

One of the most pervasive challenges is data fragmentation: important information about components is often siloed across organizations using incompatible formats, with little reason for sharing due to commercial competition or unclear data governance. As a result, stakeholders struggle to establish a "single source of truth" for part source, airworthiness, or usage history. In severe cases - such as the

GoAir insolvency - failures in part availability and delayed procurement were cited as major contributors to grounding significant portions of fleets.

Furthermore, the Indian MRO ecosystem, despite its projected growth at a CAGR of 8.9% (SP's AirBuz, 2020), continues to lag behind global peers in terms of automation maturity, specialized capabilities, and access to critical components. While some advancements have been made in predictive maintenance and digital twins, the majority of workflows still rely on physical documentation, manual inspections, and reactive maintenance. This translates into suboptimal resource management, longer lead times, un-optimized inventory, and difficulty in validating component resale or reuse due to missing/inaccessible to a trusted aircraft history.

Overlaying this operational complexity is the issue of supply chains. With numerous actors, limited interoperability, and little end-to-end SLA visibility, the aviation aftermarket remains vulnerable to inefficiencies, fraud, and supply mismatches. The absence of a verifiable, tamper-proof record for part lifecycle data allows for entry of grey-market resellers and counterfeit parts, ultimately risking passenger safety and damaging OEM, lessor, or airline reputations (Leach & Bird & Bird LLP, 2018).

A core issue is data fragmentation. Maintenance records and part histories are stored in silos across OEMs, airlines, lessors, and MROs, each using dissimilar formats and proprietary systems. In a competitive industry with ambiguous data governance, this results in operational blind spots and wears away the ability to verify airworthiness or part pedigree (Accenture & Thales, 2018). In extreme cases, like the GoAir insolvency, such breakdowns in traceability and procurement led to fleet groundings due to part unavailability.

While traditional MBSE modeling captures system behavior and stakeholder needs well, it lacks built-in mechanisms for trust, traceability, and real-time consensus across decentralized stakeholders. Blockchain complements this gap by embedding verifiable, tamper-proof data exchanges into the operational model. In addition to this, it is only MBSE that can enable an end-to-end traceability and impact analysis before we actually implement it.

While blockchain has often been proposed as a "silver bullet" to address these challenges (MRO Blockchain, n.d.), most discussions fail to clearly map how such a solution would embed into the operational fabric of MROs and other aviation stakeholders. Instead of proposing architecture prematurely, this paper advocates a Model-Based Systems Engineering (MBSE) approach to conduct a structured operational analysis. Using tools like Capella and the Arcadia methodology, we define actors, capabilities, and inter-entity activities to reveal where blockchain could add verifiable value within existing aviation MRO operations.

This paper aims to lay a foundational operational model that evaluates the feasibility and integration pathways of blockchain - not as hype, but as an enabler of trustworthy automation and traceability in aviation MRO. Future work will extend this by proposing a Consortium Architecture and validating the model through stakeholder feedback and pilot implementation scenarios.

Problem Statement and Scope

The Core Problem

While MBSE provides a structured way to model complex systems and stakeholder interactions, it does not inherently resolve challenges related to trust, traceability, and decentralized coordination, especially in multi-stakeholder environments like aviation MRO. By integrating blockchain into the MBSE-driven architecture, this work enables secure, transparent, and verifiable exchanges between actors, addressing issues such as data silos, manual reconciliations, and delayed handovers. Without this layer, traditional models remain limited to assuming data integrity rather than enforcing it.

Presently, there is no structured, model-based operational analysis guiding the implementation of blockchain in aviation MRO. This leads to poor alignment between technology capabilities and actual operational needs, resulting in fragmented adoption, ROI uncertainty, and resistance from stakeholders.

Today, no structured operational model exists to guide blockchain adoption in MRO. As a result, most implementations are either narrowly scoped or driven by technology-first thinking, resulting in misalignment between capabilities and real-world stakeholder needs. This paper addresses this by applying MBSE during the Operational Analysis phase, using Capella and the Arcadia methodology to explicitly define roles, workflows, and data exchanges. In doing so, we aim to identify where blockchain adds actual verifiable value.

Key Challenges current Aviation industry faces

1. *Lack of End-to-End Traceability*: Inability to verify the full lifecycle of high-value parts across multiple MRO events and stakeholders.
2. *Siloed Data and Manual Processes*: Aircraft component data, maintenance logs, and compliance information are fragmented and often paper-based.
3. *Poor Cross-Stakeholder Trust*: Airlines, OEMs, lessors, and MROs often lack incentive or infrastructure to share data securely and transparently.
4. *Limited Process Automation*: Absence of trusted digital triggers (e.g., validated logs) inhibits workflow automation across procurement, certification, and recordkeeping.
5. *Opaque Supply Chain Visibility*: No unified view across parts manufacturers, resellers, and service providers leads to misaligned inventories and reactive sourcing.
6. *Fragmented Standards and Governance*: The absence of a common operating model or data-sharing standard across MROs impedes scalable adoption.

Scope of the Paper

This paper focuses specifically on the Operational Analysis phase within an MBSE framework, applying it to the context of blockchain adoption in MROs. We do not directly propose a solution architecture - instead, we:

- Model key operational entities within the MRO and Blockchain ecosystem using Capella and Arcadia methodology.
- Map operational capabilities and activities to define how business processes currently function.
- Identify pain points and interface gaps that can potentially be addressed through blockchain-enabled trust, automation, and traceability.
- Structure system-of-interest boundaries, enabling future development of a Consortium Architecture in subsequent work.

The aim is to demonstrate the utility of MBSE in navigating complex socio-technical systems and in grounding emerging technologies like blockchain in the operational realities of aviation MRO.

Model-Based Systems Engineering (MBSE) provides the only structured, scalable methodology for adopting emerging technologies like blockchain in complex, safety-critical domains such as aviation MRO. Through standardized modeling of stakeholder objectives, information flows, and operational scenarios, MBSE enables technology adoption to be driven by need, not novelty (Estefan, 2007; INCOSE, 2023).

Specifically, using MBSE in the Operational Analysis and Logical Architecture phases (as formalized in ARCADIA methodology and supported by tools like Capella) helps stakeholders model who needs what data, when, and under what constraints (Roques, 2017). This structured view is essential to defining blockchain-appropriate use cases, where trust is low, processes are audit-intensive, and stakeholders are decentralized ((Efthymiou et al., 2022)).

Without MBSE, blockchain adoption risks being driven by vendors or isolated pilots. With MBSE, it becomes part of a systems-led transformation that aligns technical capabilities with verified operational needs (Accenture & Thales, 2018).

Methodology

To reinforce the selection of MBSE over traditional approaches in the context of blockchain integration, a structured comparative evaluation was performed. This involved defining evaluation attributes such as traceability, regulatory readiness, inter-organizational coordination, risk containment, scalability, and architecture clarity. Each method, Ad Hoc, Document-Based Systems Engineering (DBSE), MBSE, and MBSE + Blockchain was assessed against these attributes using a relative scoring approach based on literature review and domain-specific implementation feasibility.

A simple scoring rubric (1 = Poor, 3 = Moderate, 5 = Fair, 9 = Strong) was used to benchmark each method. The scores reflect the expected capability and deployment challenges of each method in handling blockchain's requirements within the aviation MRO ecosystem. The results are presented in Table 1, showing the superior capability of MBSE in providing a structured, traceable, and scalable framework for such integration.

Attribute	Ad Hoc Approach (Unstructured)	Document-Based SE (DBSE)	MBSE Only	MBSE + Blockchain
Stakeholder Alignment	Fragmented	Partial	Strong	Highest
Trust Modeling	Not Represented	Vague	System-Level	Process + Trust Logic
Traceability	Manual and Unreliable	Semi-Automated	Model-Based	Immutable + Modeled
Regulatory Compliance Modeling	Post-facto Audits	Manual Mapping	Included	Enforced + Auditable
Scenario Simulation (What-If Analysis)	Not Possible	Limited	Moderate	High Fidelity
Inter-Organizational Workflow Modeling	Absent	Text-Based	Limited	Executable Contracts
Digital Thread Readiness	None	Not Scalable	Pre-Enabled	Seamless
Cost of Integration	High (4/5)	Medium-High (3/5)	Medium (2/5)	Low (1/5)
Scalability for Consortium Use	Not Feasible	Risky	Possible	Designed-In
Change Impact Analysis	Ad-hoc	Manual	Traced	Traced + Enforced
Time to Operationalization (Minimum)	~24–30 months	~18–24 months	~12–15 months	~9–12 months

Table 1. MBSE + Blockchain outperforms traditional methods across key operational and system-level attributes relevant to aviation MRO

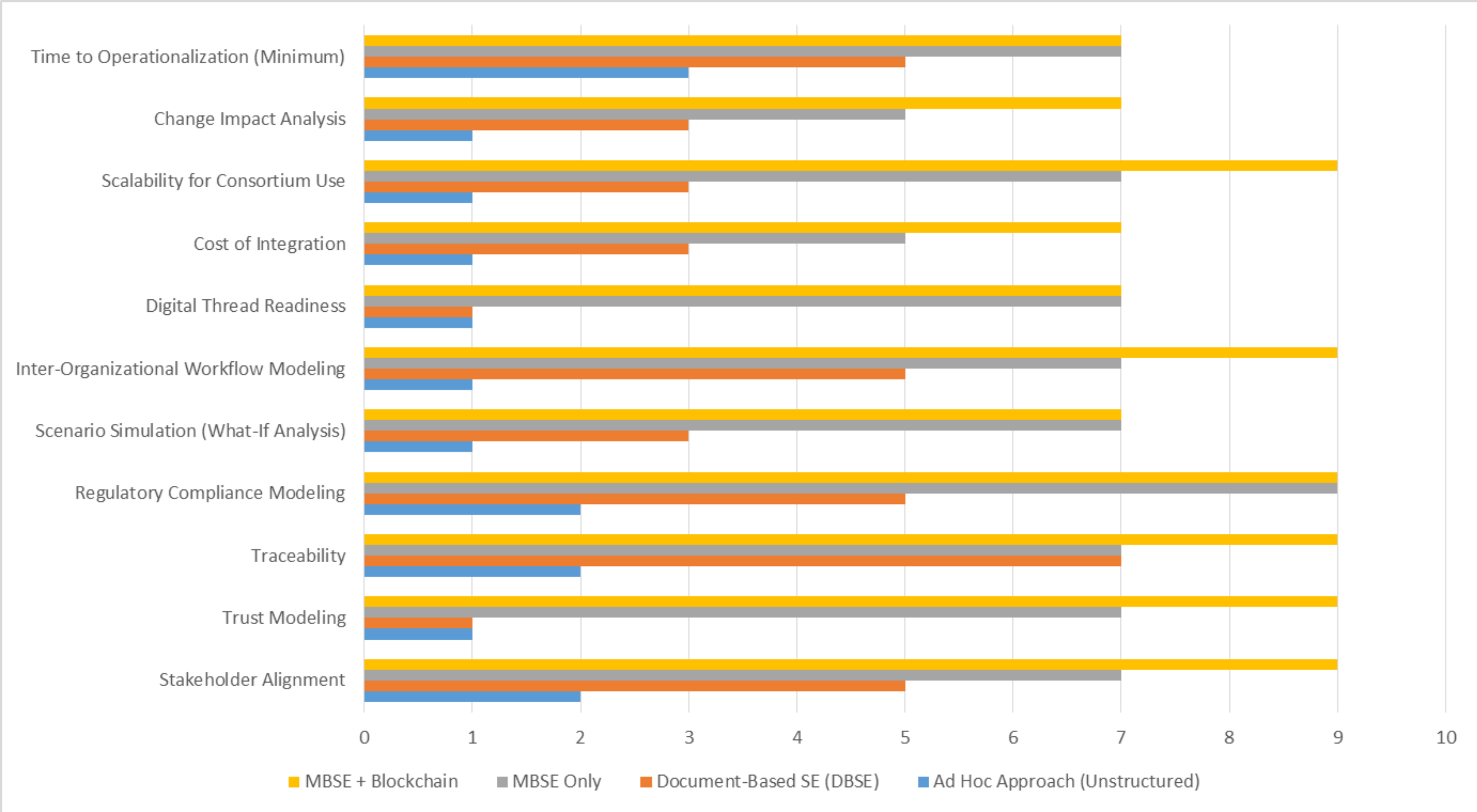

Figure 1. Scoring rubric for comparative evaluation (1 = Poor, 3 = Moderate, 5 = Fair, 9 = Strong)

To illustrate the maturity progression and capability uplift, Figure 1 introduces a maturity chart showing how system capability and clarity evolve as teams transition from unstructured methods toward MBSE-based integration. The diagram underscores the inherent limitation of traditional SE approaches, such as:

- Lack of end-to-end traceability (DBSE fails to connect operational needs to system realization),
- Poor handling of complex inter-domain interactions,
- No inherent simulation or validation support for distributed trust mechanisms.

Attribute	Ad Hoc Approach (Unstructured & Traditional)	Document-Based SE (DBSE)	MBSE Only	MBSE + Blockchain
Stakeholder Alignment	No structured modeling; alignment depends on personal communication and siloed documents	Documents help align some teams but lack dynamic synchronization or common modeling language	Shared system models (e.g., SysML) align stakeholders through visual, traceable artifacts	Models + blockchain-backed consensus create trustable, shared source-of-truth
Trust Modeling	There is no formal system or model to represent trust logic	Trust assumptions may be buried in textual documents or contracts; not explicitly modeled	System trust assumptions can be modeled using formal requirements and behaviour diagrams	Smart contracts and blockchain consensus explicitly enforce trust and integrity
Traceability	Traceability, if attempted, is spreadsheet-based or tribal knowledge; prone to error	Tools like DOORS may support requirements traceability but not across full lifecycle artifacts	End-to-end traceability exists across requirements, design, analysis, and test artifacts	In addition to MBSE, blockchain ensures tamper-evident traceability of transactions and records
Regulatory Compliance Modeling	Compliance is proven after the fact through manual documentation checks	Document-based traceability helps, but requires manual effort to demonstrate compliance	Regulatory needs can be modeled into requirements and validated via simulations	Blockchain provides tamper-proof audit trails, making compliance provable and real-time
Scenario Simulation (What-If Analysis)	No models to simulate or analyze; decision-making is gut-based or past-experience-driven	Some analysis tools may exist, but disconnected from the system architecture	SysML and modeling tools can run limited functional and behavioral simulations	With real-world data and smart contract simulations, scenario testing is both high-fidelity and validated
Inter-Organizational Workflow Modeling	No shared view or model of how multiple orgs work together; leads to chaos	MoUs or SLAs may define workflows, but they are non-executable and hard to trace	MBSE can model interactions but not enforce or automate them	Smart contracts can automate and enforce inter-org workflows with transparency

Attribute	Ad Hoc Approach (Unstructured & Traditional)	Document-Based SE (DBSE)	MBSE Only	MBSE + Blockchain
Digital Thread Readiness	No continuity or lifecycle integration of data; no digital thread at all	Hard to manage beyond one or two engineering domains; breaks at scale	Provides continuity across design and V&V, enabling digital thread formation	Blockchain adds trust, traceability, and immutability to the digital thread, enabling secure continuity across orgs
Cost of Integration	Lack of standardization causes major rework, firefighting, and integration chaos	Some reuse and documentation help, but inefficiencies still abound	Upfront cost is moderate due to modeling overhead, but pays off through fewer downstream errors	Initial setup is expensive but streamlined integration and zero-trust architecture save major cost in the long run
Scalability for Consortium Use	Cannot scale across multiple companies or regulators; no trust foundation	Might work within a company, but breaks down across organizational boundaries	Enables controlled scaling via standard models and tooling	Blockchain inherently supports decentralized collaboration with tamper-evident records
Change Impact Analysis	Changes ripple in unpredictable ways due to undocumented dependencies	Traceability helps, but change impact needs human analysis	Model dependencies enable better automated impact analysis	Changes can be programmatically tracked and enforced via smart contracts and consensus
Time to Operationalization (Minimum)	High time due to chaos, rework, and unclear requirements	Slightly better than ad hoc, but still involves silos and inefficiencies	Structured approach accelerates integration, V&V, and testing	Combines MBSE's modeling clarity with blockchain's workflow automation and trust-building to dramatically reduce time

Table 2. Rationale for evaluated ratings

Based on the evidence above, this study adopts a Model-Based Systems Engineering (MBSE) approach adopting blockchain to conduct a structured operational analysis for evaluating the integration of blockchain technology within the aviation Maintenance, Repair, and Overhaul (MRO) domain. MBSE enables a shift from traditional document-based analysis to a model-centric approach, allowing system-level behaviors, responsibilities, and interactions to be explicitly captured, traced, and validated.

The methodology follows a top-down decomposition, beginning with the Operational Analysis phase of the system lifecycle. The objective is to understand how current MRO workflows operate, identify systemic inefficiencies, and evaluate how blockchain can enhance transparency, traceability, and trust without disrupting established operational boundaries.

A. Operational Scope Definition

To address the lack of integration, transparency, and data coherence within aviation MRO processes, an operational analysis approach was considered. Using the Arcadia methodology and the Capella modeling tool, we identified the major operational entities and capabilities involved in aircraft maintenance and parts traceability.

The Operational Entity Breakdown Diagram (OEBD) was used to represent key actors and systems such as the MRO and the supporting Blockchain infrastructure. Each of these operational entities was further decomposed into sub-entities reflecting their functional responsibilities, such as Work Order Management, Execution & Inspection Teams, etc shown in Figure 1.

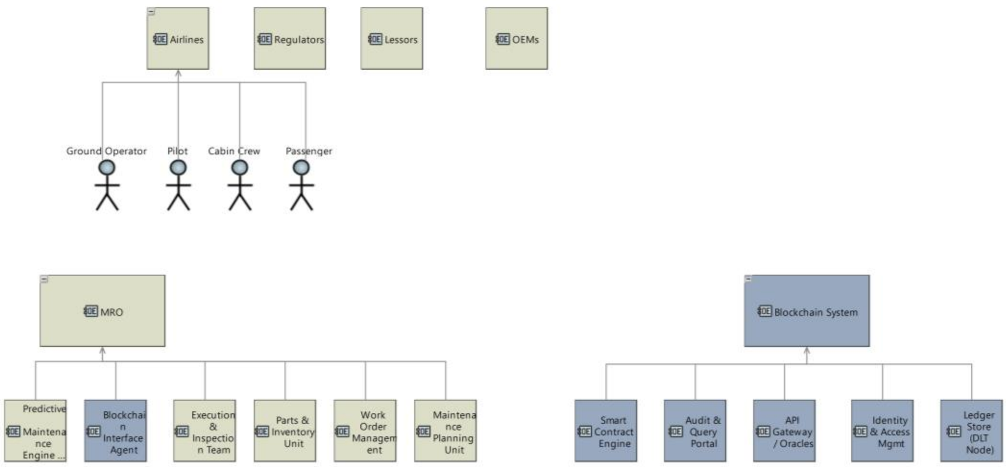

Figure 2. Operational entities identified for MRO and Blockchain roles, and their subcomponents

Following this, an Operational Capability Breakdown (OCB) was created to define what each entity must be able to do to fulfill its role. Capabilities such as “Maintenance Execution & Tracking,” “Spare Parts Traceability,” “Smart Contract Automation,” and “Audit Readiness” were identified across MRO and Blockchain domains.

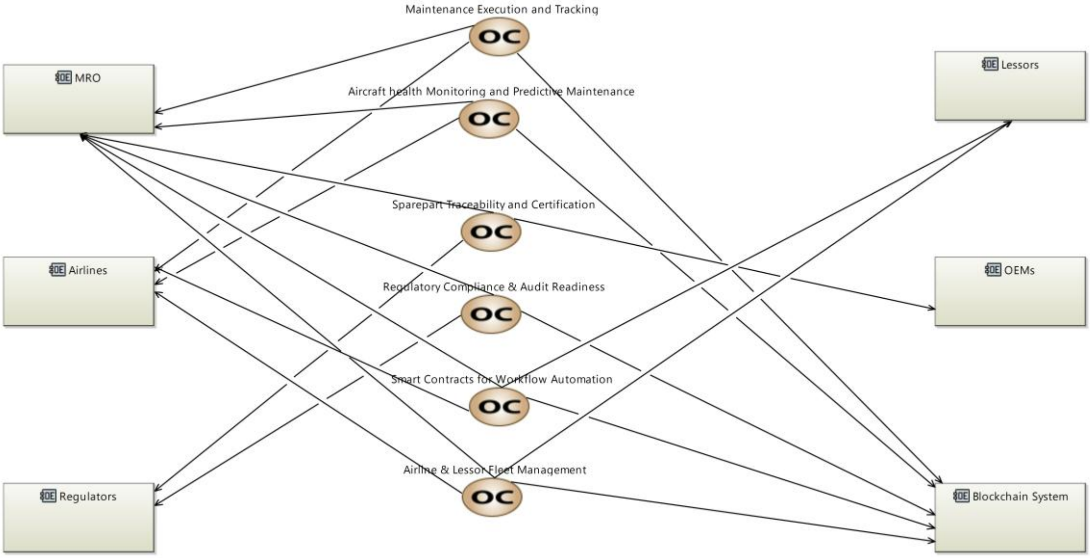

Figure 3. Capabilities modeled for the Operational

B. Detailed Operational Activities

Each operational activity was further expanded into detailed root-level steps to provide clarity for implementation and simulation. These were structured hierarchically to reflect their order of execution, triggers, and interdependencies.

For instance, "1. Fault Detection" under the MRO domain includes:

1.1 Monitor Aircraft Health

1.2 Analyze Failure Signatures

1.3 Predictive Alert Generation

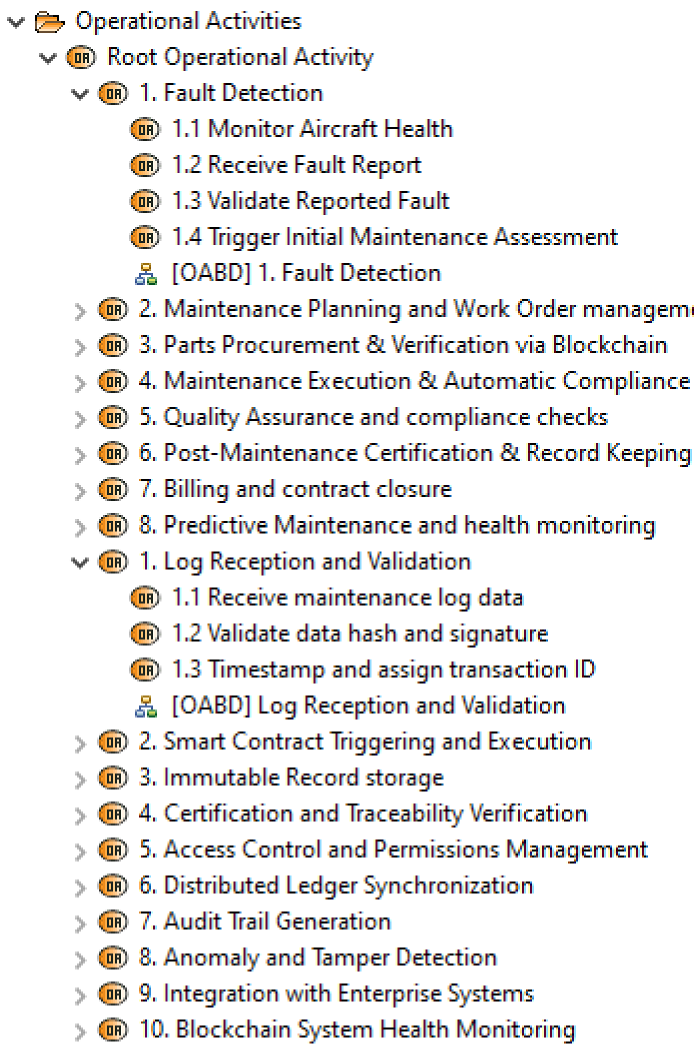

Figure 4. Detailed definition and breakdown of operational activities for MRO and Blockchain domains

This structured decomposition ensures that each activity aligns with both capability delivery and system-of-interest expectations. It also forms a traceable backbone for future scenario modeling and validation exercises. To effectively illustrate the paper-based workflows within MRO operations, the Operational Activity Breakdown (OAB) was developed as a structured decomposition of the key functions carried out by MRO and supporting blockchain systems. This breakdown enables a clear traceability from stakeholder pain points - such as lack of parts visibility, regulatory burden, and poor process automation to the operational activities that respond to them. Given the breadth of the domain and the complexity of real-world data interactions, the OAB shown in Figure 4 is a representative viewpoint - a focused "clone" of the larger model that details out critical operational scenarios relevant to predictive maintenance, part traceability, and smart contract execution. The intent is to infer how MBSE can be used to drive clarity in defining operational needs, exposing inefficiencies, and enabling the systematic development of future architectures - especially in data-intensive, high-stakes industries like aviation MRO.

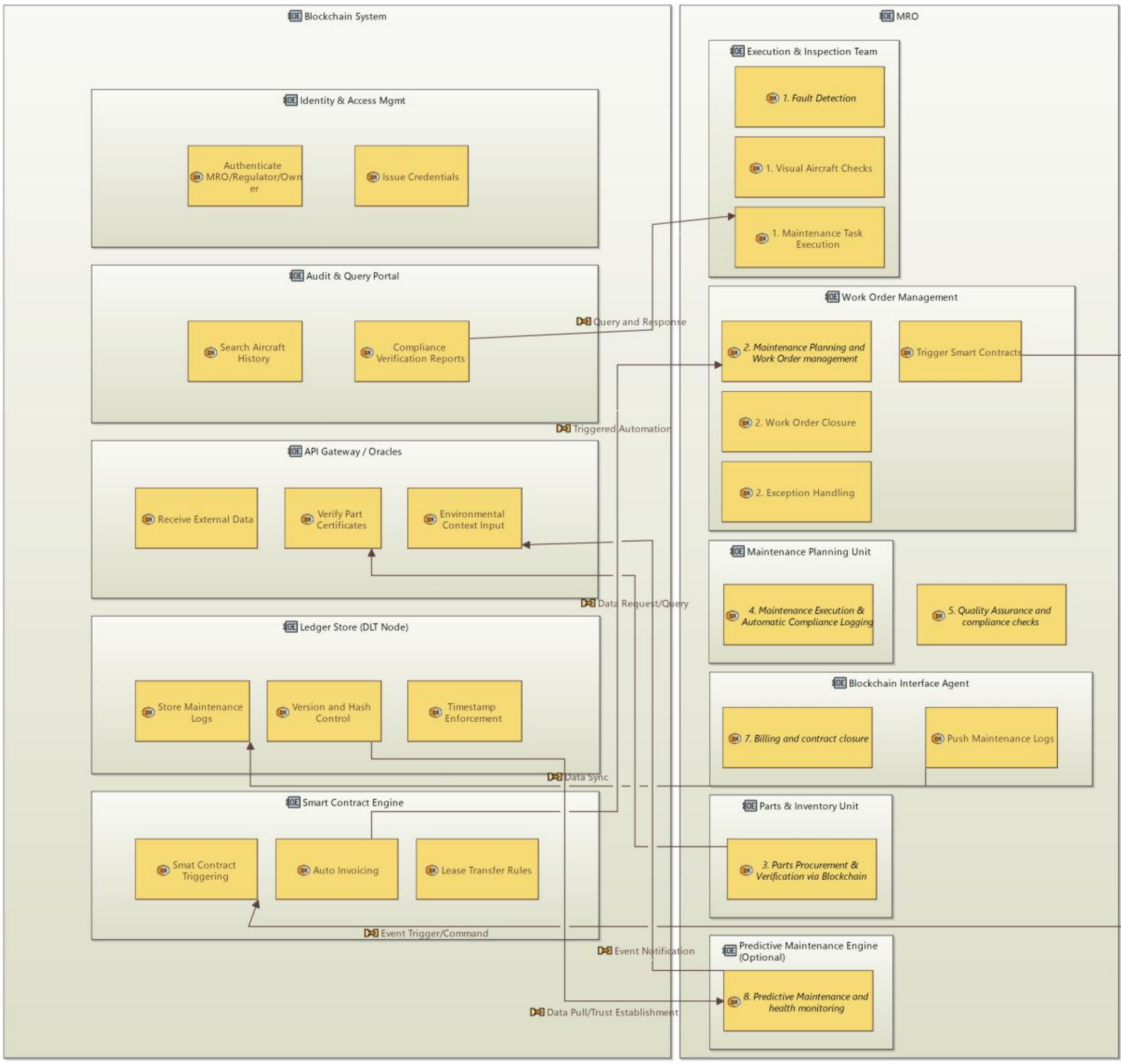

Figure 5. Operational Activity Breakdown: Integrated Blockchain-Enabled MRO Ecosystem for Aviation

C. Operational View and Interactions

High-Level operational views were generated to visualize the key mission objectives, constraints, and stakeholders. From here, operational interaction diagrams were developed to map out the information exchanges between MRO and Blockchain entities. These diagrams modeled interactions like smart contract activation upon fault detection, part authentication via distributed ledger, and Compliance reporting. The focus was on clarity and traceability of interactions, ensuring that information flows matched realistic aviation operations while enabling new digital capabilities.

This study applied a structured Model-Based Systems Engineering (MBSE) methodology to model and analyze the operational integration of Blockchain technology within aviation MRO workflows. Our approach was targeted to capture, analyze, and validate the interactions between two distinct but tightly coupled domains, MRO operations and the supporting Blockchain infrastructure.

A major insight emerged during the operational analysis, where activities across the Blockchain ecosystem and the MRO value chain were mapped into a cohesive operational view. This analysis became instrumental in surfacing interaction points and data flows that were previously opaque or only vaguely defined.

Through this analysis and Model based representations, we were able to:

- Identify how routine maintenance actions like fault detection and visual inspection could autonomously trigger smart contracts within the Blockchain system, enabling automated billing and contract enforcement.
- Reveal how external data feeds (e.g., compliance certificates, environmental inputs) act as oracles, directly influencing maintenance planning and validation processes.
- Map the interaction between parts traceability systems and Blockchain ledger nodes, demonstrating how digital part histories can be securely stored and retrieved during audits or warranty claims.
- Highlight how Blockchain enables near real-time visibility of aircraft history and maintenance compliance through a dedicated audit and query interface, streamlining oversight and regulatory reviews.
- Capture predictive maintenance logic feeding into both MRO planning tools and Blockchain systems, enabling lifecycle-based servicing and reducing unplanned downtime.

This operational analysis went beyond abstraction by providing an understanding of how Blockchain capabilities align with, and enhance, existing MRO workflows. It served as a foundation to validate assumptions, refine system boundaries, and shape the subsequent logical architecture with confidence.

The clarity and system-wide perspective gained through this modeling effort has positioned us to move toward implementation-ready designs, while also informing stakeholders of high-impact integration points.

Conclusion and Recommendation

This paper demonstrated how a Model-Based Systems Engineering (MBSE) approach can be effectively applied to analyze operational challenges in aviation MRO and evaluate the systemic value of integrating Blockchain technologies. By leveraging structured operational modeling, we identified key inefficiencies in current MRO workflows - from poor traceability and siloed data to manual, error-prone recordkeeping - and illustrated how Blockchain capabilities, such as immutable ledgers and smart contracts, directly address these pain points.

Through operational analysis, critical touchpoints between MRO entities and Blockchain systems were clarified, enabling us to visualize a future-state operation where trust, traceability, and automation are natively embedded into maintenance processes. Notably, we found that such clarity would not have been possible through traditional or document-centric systems engineering alone; the model based approach exposed gaps, interfaces, and opportunities that might otherwise remain hidden.

Key recommendations that emerged from this work include:

- Adoption of MBSE in early development phases: For organizations considering digital transformation of MRO, adopting MBSE early in the planning phase ensures that operational dependencies, risks, and value streams are fully understood.
- Envisioning operational scenarios: Constructing detailed operational views helps drive stakeholder consensus and clarifies system roles, especially when integrating emerging technologies like Blockchain.
- Validation with domain actors: While modeling provides structure, validation must be grounded in real-world feedback from MRO engineers, supply chain managers, and technology integrators.
- Modular implementation: Rather than a massive overhaul, modular introduction of Blockchain components (e.g., smart contracts for parts procurement, digital logbooks) can yield measurable value with reduced disruption. This can be envisioned only when we have different Model based stakeholder viewpoints mapped to the efforts required to establish specific methods.

This effort underscores that MBSE is not just for systems design, but a decision-support enabler that helps organizations navigate complex technology integration and transformation initiatives with confidence. For MRO operations, where reliability, compliance, and cost are vital, such structured analysis is essential.

Future Scope of Work

Building upon the operational analysis established through MBSE, the future scope of this research is directed towards developing a scalable, interoperable, and verifiable Consortium Architecture for blockchain implementation within the aviation MRO ecosystem. While the current work lays the foundation by modeling operational entities, interactions, and functional flows, the subsequent phase aims to expand this effort across multiple layers of system abstraction and stakeholder engagement. The system model is planned to be iteratively refined and validated against real-world cases of supply chain breakdowns and reactive maintenance delays (e.g., GoAir case). The validation emphasis shall be the traceability of operational needs to modeled activities and entities. Specific attention needs to be given to how the blockchain system could integrate without disrupting airworthiness workflows or regulatory compliance. Behavioral validation is planned as a future scope using simulation and scenario walkthroughs.

A key area of development involves architecting a consortium-based governance model. This includes the definition of roles, responsibilities, and contractual obligations among diverse stakeholders—MRO providers, airline operators, OEMs, regulators, and lessors. In doing so, the architecture must address issues such as data ownership, access privileges, legal frameworks, and regulatory oversight. The blockchain layer must be designed to ensure trusted interoperability while respecting competitive boundaries between organizations, particularly in contexts where information asymmetry is a challenge.

Further refinement of the MBSE model will be required to include logical, functional, and physical layers, translating operational scenarios into traceable architectural components. The functional breakdown developed in this study will evolve into a system architecture that can support executable models, enabling performance simulations and behavioral validation under varying operational conditions. This can be especially useful for stress-testing the model against real-world cases, such as the GoAir engine grounding incident, to assess the effectiveness of blockchain-enabled workflows in mitigating supply chain risks.

The proposed architecture will also benefit from the inclusion of quantitative modeling and simulation. Metrics such as turnaround time for parts procurement, documentation cycle time, audit readiness, SLA compliance, and overall system throughput can be simulated and compared in pre- and post-blockchain scenarios. These indicators will help build a business case for the proposed solution and validate its operational value across different stakeholder perspectives.

While this study focused on operational integration and trust modeling for digital workflows, a critical aspect that requires dedicated attention in future work is data security and control across stakeholders. As blockchain-based systems begin to span organizational boundaries covering maintenance teams, suppliers, regulators, and asset owners, the need to define who can see what, when, and under what conditions becomes paramount. Future phases of this work will explore mechanisms for granular data access control, permissioned blockchain layers, and cryptographic enforcement of stakeholder-specific visibility. This includes modeling role-based access, handling of sensitive operational and compliance data, and ensuring revocation or update capabilities without compromising the chain's integrity. We acknowledge that solving these challenges requires targeted architectural additions, such as zero-knowledge proofs, off-chain storage references, and identity management frameworks. Instead of addressing all blockchain concerns at once, we see value in tackling this in a phased manner, with data governance and control being the logical next step to ensure secure, compliant, and trusted collaboration at scale.

Another important trajectory of future work includes aligning the blockchain-enhanced model with existing aviation standards and regulatory frameworks. This includes mapping functional workflows to airworthiness and safety standards like ARP4754A, DO-178C, and DO-200B, and exploring collaboration with global regulatory bodies like FAA, EASA, and India's DGCA. Furthermore, engagement with standardization entities such as SAE, IATA, and ICAO will be crucial in evolving a trusted and unified set of guidelines for blockchain in MRO.

Finally, the integration of MBSE with digital transformation tools will be explored. This includes investigating how operational scenarios modeled in SysML or Capella can inform the logic and conditions embedded in smart contracts, potentially enabling automated traceability between system models and deployed blockchain artifacts. The research also envisions integration with broader digital thread and digital twin frameworks, thereby positioning blockchain not just as a ledger, but as a strategic enabler of traceable, auditable, and collaborative engineering ecosystems.

References

PwC. (2019), April. Data for the life of the aircraft. How the adoption of blockchain can provide a boost of power and efficiency to the aerospace industry. https://www.pwc.com/gx/en/aerospace-defence/assets/data-for-the-life-of-the-aircraft.pdf

Jaiswal, Z. S. (2020, June). *MRO opportunities and Challenges – India*. Aviation, Business Aviation, Civil Aviation Magazine from SP Guide Publications. https://www.spsairbuz.com/story/?id=1101#:~:text=This%20facet%20will%20enable%20IT,by%20providing%20MRO%20services%20globally.

Randell, P. (2025, April 9). World Aero News: MRO MANAGEMENT – FEEDING FLIGHT OR FRAUD? World Aero. https://www.worldaero.co.uk/2025/04/09/mro-management-feeding-flight-or-fraud/

2018 Form 41, Schedules P-7 and T-100, 2018 Group III Part 121 Air Carrier Costs – Direct and Indirect Costs. Economic Values for Investment and Regulatory Decisions

MRO blockchain. (n.d.). https://www.sita.aero/resources/White-papers/mro-blockchain/

Leach, M. & Bird & Bird LLP. (2018). Managing and exploiting Big Data in the Aviation Sector: Legal Implications and Challenges. In IATA 5th Paperless Aircraft Operations and RFID Conference. https://www.iata.org/contentassets/fafa409c883d41198aeb87628c848851/1430_mark_leach_managing-and-exploiting-big-data-in-the-aviation.pdf

Accenture and Thales demonstrate how blockchain technology can secure and simplify aerospace & defense supply chains. (n.d.). https://newsroom.accenture.com/news/2018/accenture-and-thales-demonstrate-how-blockchain-technology-can-secure-and-simplify-aerospace-and-defense-supply-chains

Survey of Model-Based Systems Engineering (MBSE) Methodologies (2007), Jeff A. Estefan, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, U.S.A.

Roques, P. (2017). Systems Architecture Modeling with the Arcadia Method: A Practical Guide to Capella. Elsevier.

Efthymiou, M., McCarthy, K., Markou, C., & O'Connell, J. F. (2022). An exploratory research on blockchain in aviation: the case of Maintenance, Repair and Overhaul (MRO) organizations. Sustainability, 14(5), 2643. https://doi.org/10.3390/su14052643

Biography

Prabhudutta Dash. Prabhu leads the Commercial Aerospace at BlueKei Solutions. His background spans complex system definitions, cross functional leadership, and strategic product development across domain.