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AN AUTOMATION ARCHITECTURE FOR REAL-TIME TRACEABILITY AND RAPID SPACE SYSTEM CERTIFICATION WORKFLOWS

Abstract

The rapid expansion of the global space infrastructure is currently challenged not by physics but by certifications. While spacecraft development cycles have accelerated, regulatory workflows remain manual and document-centric, with licensing timelines often spanning 180 days to over two years.

This paper introduces an automation architecture designed to transition space systems from reactive milestones to continuous, parallel certification.

At its core, this framework uses a Centralized Knowledge Graph built upon a formal Systems Engineering Ontology that represents entities such as requirements, subsystems, interfaces, verification artifacts, validation results, and failure modes. Engineering activities, including document revisions, simulation outputs, communication records, and task updates, are captured as events and automatically logged by the system.

Each event updates the knowledge graph, establishing bidirectional traceability across engineering artifacts. Named Entity Recognition is applied to event logs to identify and classify entities, which are then assigned indexed identifiers to maintain structured relationships throughout the engineering lifecycle.

To ensure computational efficiency, the system detects changes between document versions and routes only modified sections for entity extraction and compliance validation instead of reprocessing entire events. Natural language processing and rule-based checks are applied only to these updates, enabling incremental reasoning while preserving traceability across evolving design states.

Compliance validation is performed through a hybrid monitoring architecture that integrates rule-based verification, statistical monitoring, and machine-learning anomaly detection to enforce certification requirements derived from regulatory standards, deviations in test results, and verification workflows. Compliance checks follow a triple-layer anomaly detection pipeline that prioritizes rule matching and statistical drift analysis before escalating to supervised machine learning for complex cases. Decision pathways are reconstructed through graph-based backtracking, producing transparent explanations and audit-ready traceability for every certification outcome. A human-in-the-loop oversight layer enables engineers and certification authorities to review flagged anomalies and validate automated compliance decisions.

Preliminary analysis indicates reduction in computational requirements by 60-90% compared with conventional MBSE and PLM platforms such as Cameo Systems Modeler. The framework can also

reduce large language model utilization by 80-90% and shorten certification cycle times by 50-80%, shifting compliance validation from years to minutes.

Unlike the previous version submitted to IAC 2025, this engineer-centric and event-driven approach supports sustainable and resilient space infrastructure while aligning with the goals of the UN SDGs 9 and 16. By unifying global standards, this framework provides the infrastructure necessary to sustain the next generation of rapid, high-cadence space missions.

Declaration on the use of Generative AI and AI-assisted Technologies in the writing process

Used AI for grammatical corrections.