Digital Twin-Digital Thread Use Case Catalog

A Reference Resource

Release 1.1

March 2026

Industry Organizations

Solution Providers

Abstract

An Aerospace & Defense PLM Action Group (AD PAG)-sponsored project team undertook the challenge of advancing industry's awareness and understanding of the current practical value potential of digital twin-digital thread (Dtw-Dth) investment. They did this by benchmarking use cases using commercially available Dtw-Dth solutions, including software and services. Domain experts from AD PAG member companies partnered with four industry organizations and engaged with seven leading solution providers to execute the benchmarks.

An initial set of use cases was proposed by domain expert members of the AD PAG Digital Twin-Digital Thread project team. All four partnering organizations contributed use cases from their internal Dtw-Dth project libraries. The use case selection and refinement process with each of the solution providers followed a structured, collaborative approach to ensure the most relevant and well-defined scenarios were chosen for demonstration. In the end, 28 use cases were selected for demonstration.

This document is offered to the PLM community as a reference resource that captures all 80 use cases created and assembled in the course of the benchmark project. That includes the initial set of use cases drafted by the AD PAG Dtw-Dth project team plus the use cases contributed by the partnering organizations and the use cases negotiated with the participating solution providers.

Preface

The intent of this document is to provide an extensive catalog of digital twin and digital thread (Dtw-Dth) use cases to Product Lifecycle Management (PLM) professionals from industry, academia, government, and the solution provider community engaged in examining the nature and potential value of solutions in this domain. This catalog was created in support of a benchmark study on the topic of Dtw-Dth commissioned and conducted by the Aerospace & Defense PLM Action Group (AD PAG) with contributions from four industry organizations and participation of seven solution providers. The use case submissions have been transcribed into a common format for ease of interpretation and reuse. This compilation is now offered for the benefit of the community from which it was assembled. We encourage the reader to contact any AD PAG member, partnering industry organization, participating solution provider, or CIMdata to share your thoughts on this document and on the topic of Dtw-Dth.

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Revision Record

Revision	Date	Description
1.0	March 2026	Initial Release
1.1	March 2026	Abstract revised

To ensure AD PAG publications continue to address the most critical industry challenges, we invite your perspective on this publication. [Time to complete: < 60 seconds]

Provide Strategic Feedback

Digital Twin-Digital Thread Use Case Catalog

Introduction

This document is a reference resource of curated use cases created and assembled in the course of a digital twin-digital thread (Dtw-Dth) solution evaluation benchmark sponsored by the Aerospace & Defense PLM Action Group (AD PAG) member companies.

Background

The AD PAG engaged with a select set of Dtw-Dth solution providers to assess the capabilities of commercially available Dtw-Dth solution offerings, including software and services, through a series of use case demonstrations. This Dtw-Dth benchmark was the culmination of a multiyear AD PAG project workstream to define and characterize the potential value of Dtw-Dth investment within the A&D industry.

The AD PAG Dtw-Dth project team developed standard templates and drafted an initial set of use cases as the first stage in their plan for conducting the benchmark.

To increase the brainpower applied to this initiative and expand the consensus on the results within the A&D PLM ecosystem, the AD PAG Dtw-Dth team sought and secured agreements for collaboration and contribution of use cases from four industry organizations that are deeply engaged in examining the nature and potential value of digital twins and digital threads.

- AIAA - Digital Engineering Integration Committee (DEIC)
- OMG, Digital Twin Consortium (DTC), A&D sub-team
- prostep ivip, Collaborative Digital Twin (CDT) working group
- SAE International, G-31 Digital Communications Committee

Subsequently, a broad range of solution providers were invited to demonstrate use cases from their own current catalog that were aligned with the AD PAG-assembled use case catalog. This approach for use case selection reduced cost and lead time and focused the evaluation on the strengths of each participating provider's solution. Seven solution providers accepted the invitation and agreed to participate.

- Ansys (part of SYNOPSYS)
- Capgemini
- Cortona3D
- eQ Technologic
- Hexagon
- Infosys
- PROSTEP AG

All use cases received from partnering industry organizations and participating solution providers were transcribed to the standard templates developed by the AD PAG Dtw-Dth project team. Those use case templates are included within an Appendix to this document.

The use case write-ups for digital twin and digital thread are presented in separate sections. At the beginning of each section there is a tabulated list of the use case write-ups in the section. This table serves as a directory, and each line item contains a link for navigation to the enumerated use case write-up.

Definitions

This section presents the AD PAG definitions of digital twin and digital thread that were developed based on research in earlier phases of work by the AD PAG Dtw-Dth project team.[1]

Definition of Digital Twin

A digital twin is a virtual representation of a physical entity, its behaviors, and the associated processes used to create it. This includes the concept and design phases of a product or system development. It is an integration of data from various sources (i.e., digital thread) that defines a future, existing, or historic item, system, process, or service and operational environments.

Such representation, augmented with field data, provides a means of visualizing, understanding, predicting, and optimizing various aspects of the physical entity's design and behavior, as well as its fabrication, assembly, and the environment in which it is/was/will be used, maintained, and disposed of. Ultimately, a digital twin is expected to experience every event that its physical twin experiences, and it can be used to explore situations that a physical twin has not yet experienced.

Definition of Digital Thread

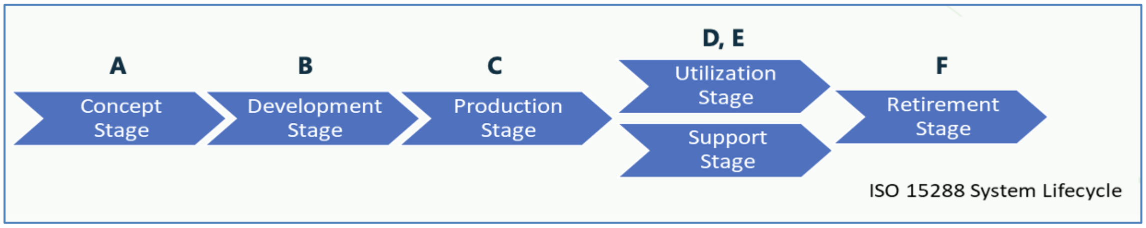
The digital thread is a communication framework that enables connected data flows for the integrated view of lifecycle artifacts and their resulting asset's data (i.e., digital twin) across traditionally siloed functional product lifecycle domains. This communication framework depends on standardized, model-based representations and semantic data modeling to facilitate the dynamic creation of context, based on multiple viewpoints. As the asset is produced, operated, maintained, and progressed through its lifecycle stages, the digital thread fabric is continually expanded to holistically merge the digital and physical worlds.

[1] Digital Twin/Digital Thread Solution Definition for Aerospace and Defense: Phase 2, Position Paper, July 31, 2022 is available at https://www.cimdata.com/en/aerospace-and-defense/publications/digitaltwin-digitalthread

Use Cases

The use cases are presented below in two sections: digital twin and digital thread. For ease of navigation, the use cases are first listed in an index table with key information, including the contributing organization, title, description, and applicable lifecycle stage(s).

Each stage is represented by a letter: A - Concept Stage, B - Development Stage, C - Production Stage, D - Utilization Stage, E - Support Stage, F - Retirement Stage. As shown in these tables, use cases typically span more than one lifecycle stage.



The use cases have been documented utilizing common templates. The level of detail varies substantially. Some use case write-ups specify no more than a title, description, and goal. Others are very detailed with documentation of scope in several dimensions, sequence of activities and outcomes, and supporting diagrams of various types.

As noted earlier, the templates used to document the use cases in common form are presented in the *Appendix: Digital Twin-Digital Thread Use Case Templates*.

Digital Twin Use Cases

The digital twin use cases are sorted by subgroup. In the index table, use cases that were demonstrated are listed first, and additional use cases that were defined during the project but not demonstrated are listed after. Use cases were assigned an identifier during the project, and they are listed in numerical order within their subgroup. Each listing includes a hyperlink to the use case write-up. Following the index table, Demonstrated Use Case write-ups are presented first, and Additional Use Case write-ups are presented after.

Contributor	Digital Twin Title	Description	Lifecycle Stage	
			Dtw Development	Dtw Utilization
Demonstrated Use Cases				
Capgemini	UCDtw025: Battery Package Assembly Demonstrator for Creation of an Assembly Concept Ready for Integration	Shop floor assembly line layout simulation and planning.	A, B, C, D, E	A
PROSTEP AG	UCDtw028: OpenPDM - Bidirectional CAD Integration between Different Vendor PLMs	OpenPDM includes tools for integration and migration of data across a variety of product lifecycle management (PLM) and other engineering data systems with Commercial Off the Shelf (COTS) connectors, including bidirectional integration of CAD data between different vendor PLM systems (Windchill, 3DX, Teamcenter) Multiple different vendor systems' PLM, are utilized within the enterprise for managing mechanical design; this variety of systems may be the result of mergers, program-specific tools or chosen for compatibility of the mechanical design tool with the PLM vendor tool	A, B, C	A, B, C

↑ View Digital Twin List ↑ View Digital Thread List

Contributor	Digital Twin Title	Description	Lifecycle Stage	
			Dtw Development	Dtw Utilization
PROSTEP AG	UCDtw029: OpenDXM GlobalX - Collaboration with External Partners	OpenDXM is a tool for automating exchange of Digital Data Packages (DDP) between partners; this supports context-based exports for native CAD and product data for engineering and manufacturing, including release data and change management for CAD modifications	A, B, C	Unlisted
Capgemini	UCDtw030: Model-Based Systems Engineering (MBSE) and Digital Twin Realization of the C-Pulse Drone	The C.PULSE Drone project demonstrates capabilities in the field of digital twin and digital thread (continuity) with a pivotal role played by Model-Based Systems Engineering (MBSE); The project comprises the following five facets: MBSE, Design, Hardware, Virtual Reality (VR), and Simulation C.PULSE showcases the integration of different technologies, such as Physics Simulations, Virtual and Augmented Reality (VR/AR), as well the enablement of real-time data exchange, leading to a digital twin realization that facilitates early validation and verification (V&V)	A, B	Unlisted
Capgemini	UCDtw031: Virtual Commissioning Automotive Demonstrator for Body-in-White Assembly Process	Showcase with an automotive use case how virtual commissioning solutions can develop and be integrated as part of a digital twin	A, B, C	A, B, C, D, E

Contributor	Digital Twin Title	Description	Lifecycle Stage	
			Dtw Development	Dtw Utilization
Ansys	UCDtw032: Modelling of Complex Multi-Fidelity, Multi-Domain, System-of-Systems (SoS) Mission Scenarios	Demonstrates SoS mission modeling to integrate and analyze multi-domain digital twins in complex scenarios. Supports lifecycle stages from concept to operations, enabling progressive model fidelity, validation and verification (V&V), and integration of software-in-the-loop/hardware-in-the-loop (SIL/HIL) systems for faster development, early issue detection, and reduced costs	A, B	C, D, E, F
Ansys	UCDtw033: Material Modeling Twins As-Built Part / Component Twins for Quality	Models/simulations of the material structure (e.g., grain structure or precipitates) that include sizes and distributions Calibration of Simulation Material Models using experimental/virtual material behavior data Part/component level models/simulations that include nonconformances and deviations from original engineering releases	A, B	C, D
Ansys	UCDtw034: Understanding the Performance of a Solar Aircraft Using Digital Twin	This demonstration illustrates how digital twins at the component and subsystem levels can be seamlessly integrated into a comprehensive system-of-systems (SoS) model	A, B	C, D, E, F
Capgemini	UCDtw035: Echo Digital Twin Application Development Framework – Vancouver International and Pearson Airports	Demonstrates the Echo Digital Twin Framework from the YVR and Pearson Projects, showcasing digital twin applications in aerospace operations, retail, security, emergency response, and asset management	A, B, C, D	Unlisted

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Contributor	Digital Twin Title	Description	Lifecycle Stage	
			Dtw Development	Dtw Utilization
Additional Use Cases				
AIAA-DEIC	UCDtw001: Digital Twin Calibration	Validation/Calibration of digital twins based on real-world product operational data/ conditions (e.g., coupon tests, wind tunnel tests, ground tests, flight tests, operational tests); digital twin calibration examples follow: 1) **Ops Analysis** - Models to develop mission planning survivability, and tactics 2) **Structural** - Finite Element Model (FEM) for Loads and Life management 3) **Variation** - Reflecting tolerances and variation in parts and tooling to identify statistical fit issues ahead of first article 4) **Vehicle Systems** - Modeling and simulation of product systems/subsystems 5) **Flight Controls** - Modeling and simulation of vehicle flight controls 6) **Mission Systems** - Modeling and simulation of mission systems/software 7) **Signature** - Model that captures initial design and repairs that impact Radar Cross Section (RCS) 8) **Sustainment** - Modeling and simulation of product sustainment	Unlisted	Unlisted

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Contributor	Digital Twin Title	Description	Lifecycle Stage	
			Dtw Development	Dtw Utilization
AIAA-DEIC	UCDtw002: Performance Monitoring, Validation, and Optimization	Virtually validate product performance while also showing how products are currently acting in the physical world to optimize performance Embed Serial Number adapted closed-loop controls for operational and environmental factors to operate closer to performance boundaries	B	B
AIAA-DEIC	UCDtw003: Design Optimization and Upgrade Analysis	A 10-75% reduction in cycle time improves the quality of the final manufactured product and enables faster iterations in response to customer feedback; this enables product version evaluation to determine which features provide the optimal solution Data analytics can facilitate timely analysis of volumes of data generated to provide insights into potential new products and revenue streams	B	Unlisted
AIAA-DEIC	UCDtw004: Market Gap Analysis and Capabilities	1) Analysis of alternatives for capability/need assessment 2) Reduction of time to develop and certify through high fidelity analysis from a digital twin	B	B
AIAA-DEIC - DEIC	UCDtw005: As-Built Configuration	Details of the aircraft As-Built configuration that are not associated with the engineering configuration such as serial numbers, cage codes, sustainment data loads, measurements during build, nonconformance documentation, supplier disclosures, and added inspections As-Built configuration contains nonconformance information, repairs, post-delivery article inspection requirements, supplier disclosure notifications, and factory test data required for aircraft or sustainment data loads	C	C

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Contributor	Digital Twin Title	Description	Lifecycle Stage	
			Dtw Development	Dtw Utilization
AIAA-DEIC	UCDtw006: Performance Validation and Optimization	Model of aircraft production performance, including task span times, hours per unit, and sequence of operations	C	C
AIAA-DEIC	UCDtw007: Factory Simulation	Discrete event and digital physical modelling to simulate physical factory layout, materials flow, and tooling, and to identify bottlenecks and the results of disruptions to the factory operations, such as quality or parts problems	C	C
AIAA-DEIC	UCDtw008: Material Modell ing Twins As-Built Part / Component Twins for Quality	Demonstrates material modeling using simulations of grain structure and distributions. Includes calibration with experimental or virtual material data and models that capture part-level nonconformances and deviations from engineering releases.	A, B	C, D
AIAA-DEIC	UCDtw009: Performance Monitoring	Cross-fleet, asset-to-asset, operator-to-operator performance normalization to environmental and multi-granular operational baselines	D, E	Unlisted
AIAA-DEIC	UCDtw010: Fleet Enterprise Twin	Product level (SN-specific) models/simulations which include As-Operated data (e.g., Equipment Health Monitoring and Environmental context data) to inform maintenance decisions & feedback to operator to improve performance	D, E	D, E
AIAA-DEIC	UCDtw011: Health Status Validation and Optimization	Failure prediction and predictive maintenance: • Incipient failure detection to adapt operation to life-extending mode so failure does not precede service • Predictive part needs for long-lead manufacture or distribution logistics	D, E	D, E

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Contributor	Digital Twin Title	Description	Lifecycle Stage	
			Dtw Development	Dtw Utilization
AIAA-DEIC	UCDtw012: Failure Analysis	Root Cause Analysis (RCA) based on part/component-specific full-genealogy (i.e., As-Designed, As-Manufactured, As-Operated, As-Serviced) and detailed operational use data New failure modes (unknown unknowns) are identified in operational data via unsupervised manifold learning for anomaly detection	D, E	D, E
AIAA-DEIC	UCDtw013: Condition-Based Maintenance	Feedback from sensors enables condition-based maintenance, fatigue life analysis, and severe event tracking Risk-based work scoping is based on predicted life versus service duration and interval to next service (e.g., tailored maintenance actions by individualized predicted part life and operational projection to next maintenance event)	D, E	D, E
AIAA-DEIC	UCDtw014: End-of-Life Decision Aid	Part/component-level model evaluating As-Used versus As-Designed versus As-Repair(able)	D, E	D, E
AD PAG	UCDtw015: As-Operated Digital Twin	The As-Operated product digital twin is a digital representation of the aircraft in operation with the up-to-date configuration that simplifies access to the related data and services	C	C, D, E, F

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Contributor	Digital Twin Title	Description	Lifecycle Stage	
			Dtw Development	Dtw Utilization
AD PAG	UCDtw016: Digital Engine	This solution is an aggregate of five different software objects. It is composed of two primary parts: • Generic avatar. This is the theoretical representation of the engine, made from the As-Designed BOM characteristics and 3D models. It is built by the design offices on the development side • Digital twin. This is the physical representation of the engine, made from the As-Built BOM; it also contains eventual non-compliances and their sanctions-associated measurements One Generic Avatar can instantiate multiple digital twins	A, B, C, D, E, F	A, B, C, D, E, F
AD PAG	UCDtw017: Digital Twin Airport Operations	Aircraft operators can incur costly delays and inefficiencies due to lack of service availability while on the ground, relating to airport layouts and gate/stand allocation (e.g., ground-power, connectivity – maintenance data offload and software part upload – payload logistics, and refueling)	E	D, E
AD PAG	UCDtw018: Aircraft Performance	Aircraft performance models and estimates of key factors, such as wind, play the most crucial role in designing efficient flight trajectories for key segments of long-haul flights Currently, ground-based flight planning systems utilize aircraft-type-specific performance tables to determine fuel flows for given flight conditions and parameters, such as altitude, mass, and speed; the tables are corrected by a performance factor as the aircraft ages	A, B, D	E

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Contributor	Digital Twin Title	Description	Lifecycle Stage	
			Dtw Development	Dtw Utilization
OMG	UCDtw019: Digital Twin Extraction and Interoperability of Data Components	Specifies technical aspects related to the extraction, decoupling, trading, and benefits of data components in a digital twin ecosystem	Unlisted	Unlisted
OMG	UCDtw020: Digital Twin Framework for the Automation and Integration of Manufacturing Systems	Utilize a framework to support the creation of digital twins of observable manufacturing elements including personnel, equipment, materials, manufacturing processes, facilities, environment, products, and supporting documents	Unlisted	Unlisted
OMG	UCDtw021: System-of-Systems Digital Twins	The joint operations of digital twins of different military assets working together towards a joint common objective; this use case demonstrates the interactions between different systems, establishing the granularity of the data to be utilized by digital twins having different levels of accuracy Challenges: • Integrating multiple digital twins to create an accurate representation of the entire System of Systems (SoS) • Requiring a significant amount of data to validate the model and ensure that the model accurately reflects the behavior of the real-world system of system	Unlisted	Unlisted

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Contributor	Digital Twin Title	Description	Lifecycle Stage	
			Dtw Development	Dtw Utilization
OMG	UCDtw022: Intelligent Digital Twin	Following the presumption that a digital twin captures the behavior of is a type of simulation of a physical objects/system, an intelligent digital twin would at a minimum use artificial intelligence (AI) to simulate the physical object system's decisioning capability and human interaction with the physical object	Unlisted	Unlisted

Demonstrated Use Cases

Write-ups of the demonstrated digital twin use cases are presented below in numerical order.

UCDtw025: Battery Package Assembly Demonstrator for Creation of an Assembly Concept Ready for Integration

USE CASE NUMBER: UCDtw025	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: Capgemini	**Associated Use Cases:**
Use Case Title: *Battery Package Assembly Demonstrator for Creation of an Assembly Concept Ready for Integration*	
Description:	To increase competitivity and reduce the time-to market and development costs, a digital End-to-End (E2E) approach and solutions for manufacturing planning are leveraged to support the design and derisk the commissioning of battery package assembly lines, using a design for integration approach (Figure 1 and Figure 2)
Goal:	Reduce time to market, derisk processes and physical commissioning, as well as maintain cost overview and control of capital expenditure (CapEx)
Data:	Capgemini restricted
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Continuous utilization
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐

↑ View Digital Twin List ↑ View Digital Thread List

Roles:	Industrial Designers, Manufacturing Engineers, Safety Staff, Commissioning and Operating Staff
Preconditions:	High digital transformation level (Figure 2)
Special Requirements:	Usage of Siemens-based E2E digital capabilities (Figure 5)
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☐ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	Industrial Designers, Manufacturing Engineers, Safety Staff, Commissioning and Operating Staff
Preconditions:	High digital transformation level (Figure 4)
Special Requirements:	Usage of Siemens-based E2E digital capabilities (Figure 3)

Notes:

Figure 1 - Concept Designed for Integration

- Maximize use of out-of-the-shelf (off-the-shelf) components
- Focus on digital continuity

↑ View Digital Twin List ↑ View Digital Thread List

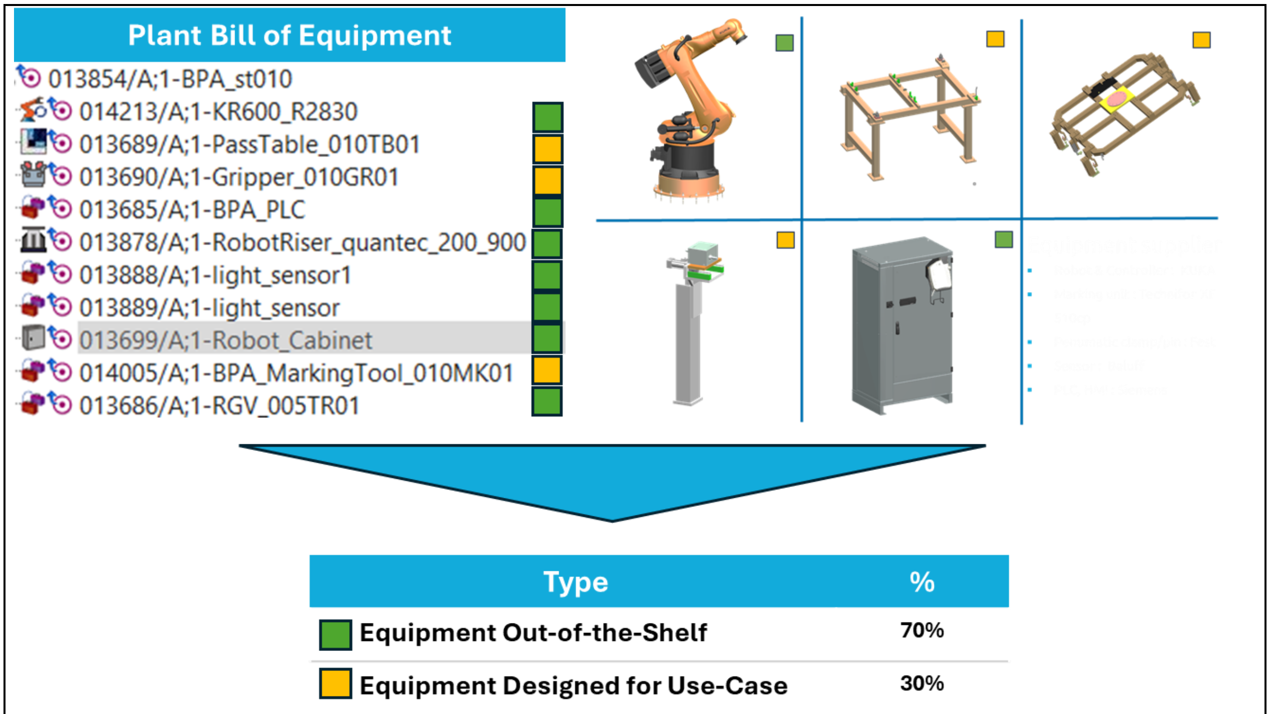


Figure 2 - High Level of Available Equipment and Production Means

- Decrease time-to-market of products
- Reduce investment
- Increase performance
- Enforce collaboration
- Reduce environmental footprint

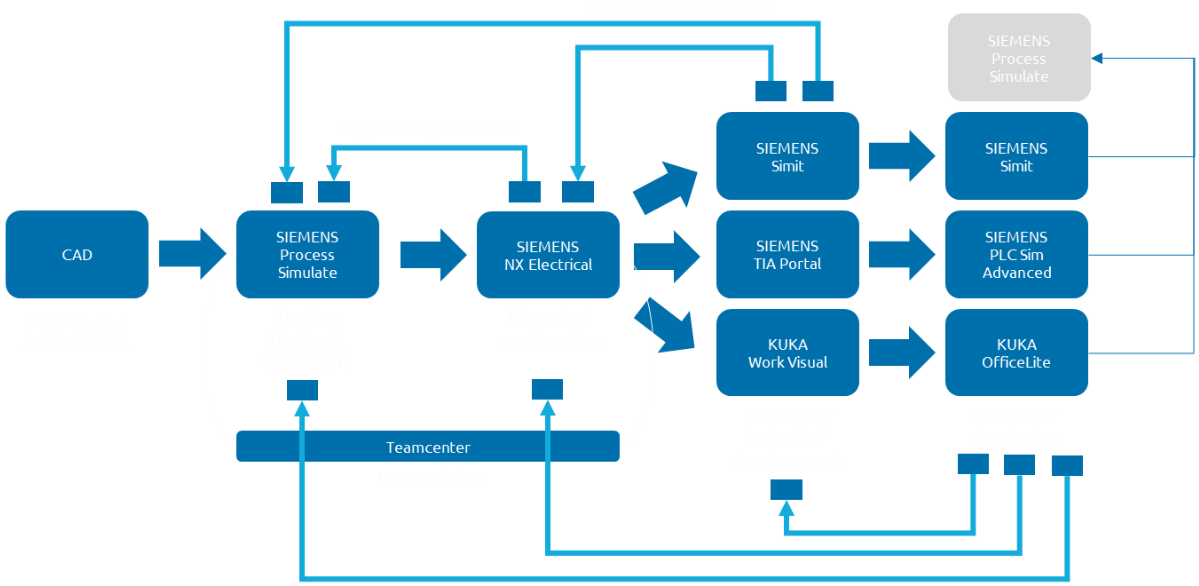


Figure 3 - Development Process

↑ View Digital Twin List ↑ View Digital Thread List

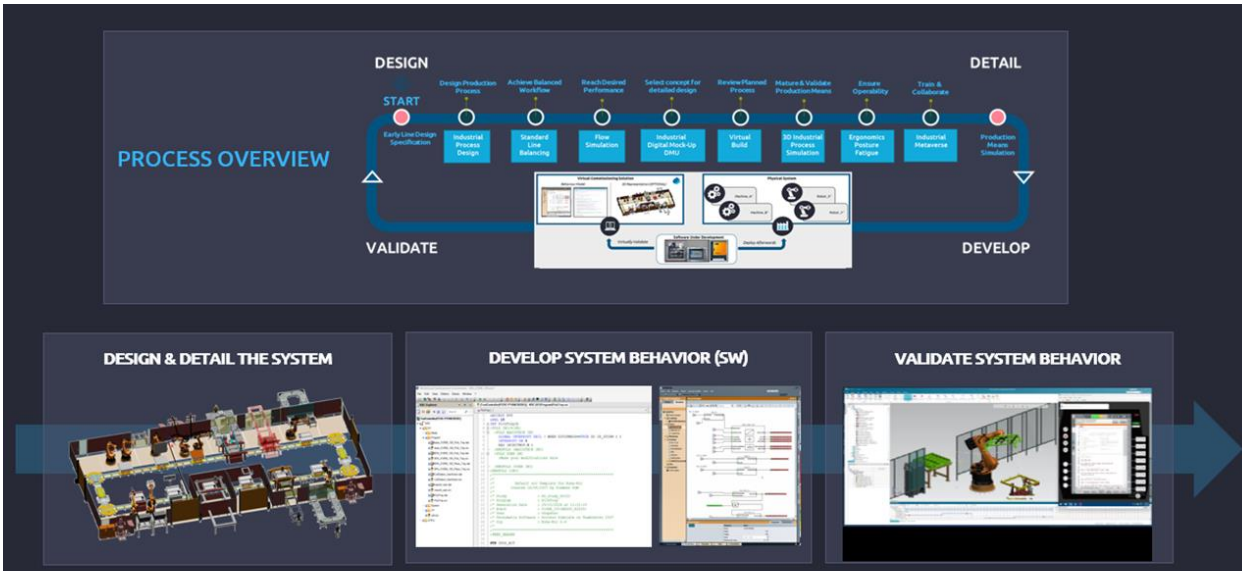


Figure 4 - Process Flow

- Derisk processes and physical commissioning through simulations in an industrial digital twin

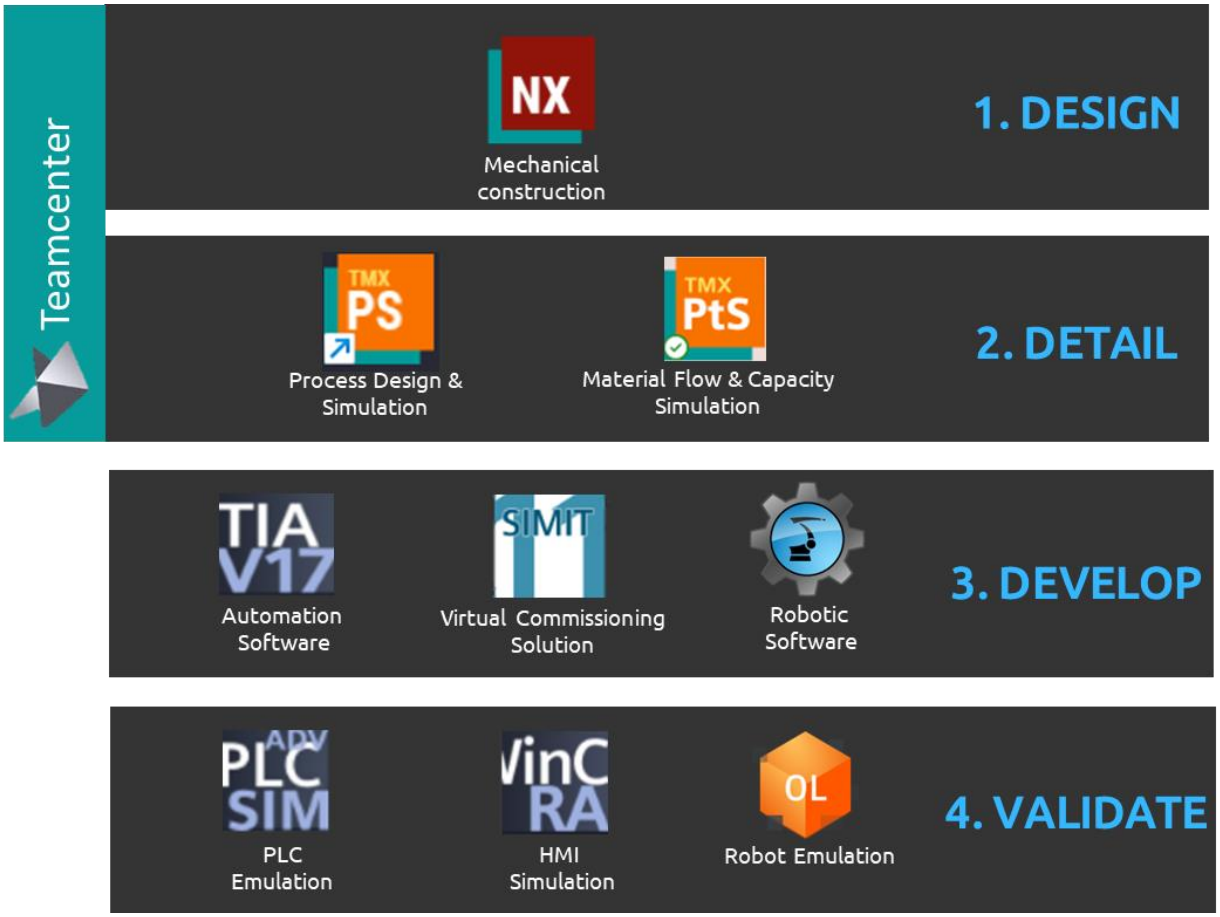


Figure 5 - Development Tool Chain

- Remain competitive
- Decrease time-to-market of products
- Reduce investment
- Increase performance
- Enforce collaboration
- Reduce environmental footprint

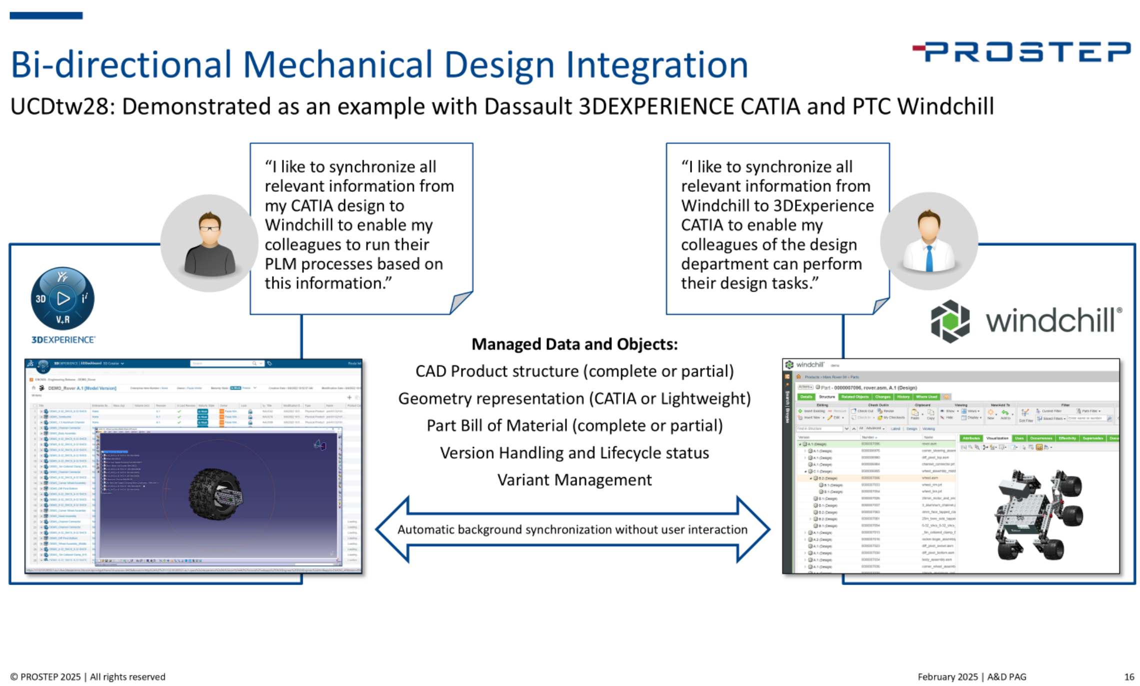
UCDtw028: OpenPDM - Bidirectional CAD Integration Between Different Vendor PLMs

USE CASE NUMBER: UCDtw028	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: PROSTEP AG	**Associated Use Cases:**
Use Case Title: *OpenPDM - Bidirectional CAD Integration Between Different Vendor PLMs*	
Description:	OpenPDM includes tools for integration and migration of data across a variety of Commercial Off the Shelf (COTS) connectors; bidirectional integration of CAD data between different vendor product lifecycle management (PLM) systems (Windchill, 3DX, Teamcenter) Multiple different vendor systems' product lifecycle management (PLM) are utilized within the enterprise for managing mechanical design; this variety of systems may be the result of mergers, program-specific tools, or chosen for compatibility of the mechanical design tool with the PLM vendor tool
Goal:	Ability to synchronize CAD and Bill of Materials (BOM) data to enable seamless collaborative digital twin between different data repositories. This enables configuration management, system analysis, and other use cases Enable mechanical design data to be synchronized between the authoring repository and other repositories, such as PLM, Simulation and Analysis Data Management (SADM), configuration management tools, or others as needed
Data:	CAD, PLM
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	Designer
Preconditions:	CAD, Part, Bill of Materials (BOM), and other datasets supporting mechanical CAD are authored and managed within a repository; this data is required to be imported to another repository to be used for PLM, verification and validation (V&V), configuration management, aggregation with other data, or other reasons
Special Requirements:	Mechanical CAD data must be usable within the source vendor systems CAD integration.
Postconditions:	Mechanical CAD data will be usable within the target vendor systems CAD integration.

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	Systems Engineer, Manufacturing Engineer

Notes:



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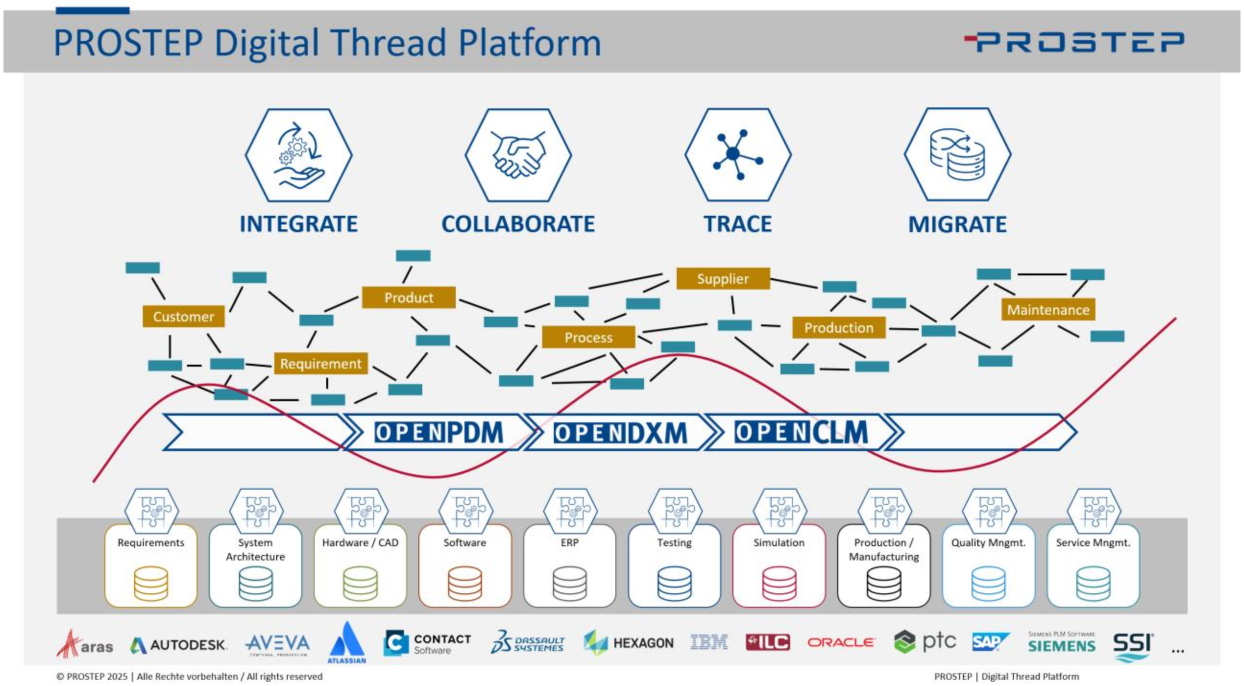


PROSTEP Digital Thread Platform for Heterogenous System Integration, Traceability, and Consistent Product Lifecycle Collaboration

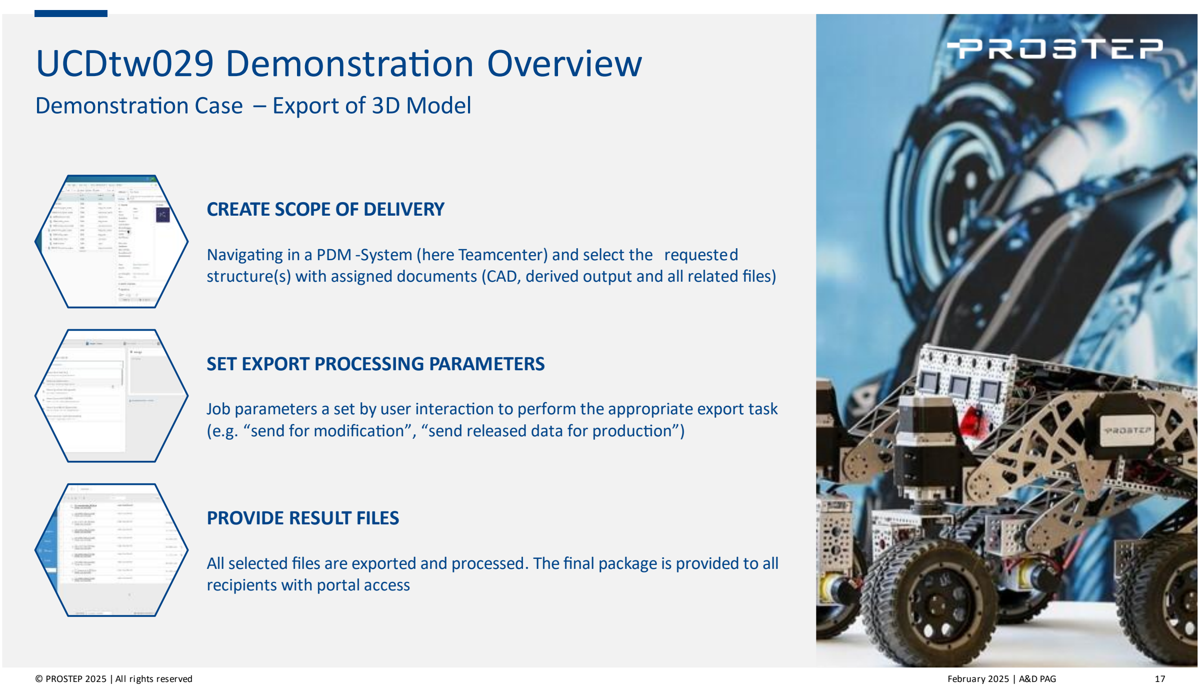
UCDtw029: OpenDXM GlobalX - Collaboration with External Partners

USE CASE NUMBER: UCDtw029	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: PROSTEP AG	**Associated Use Cases:**
Use Case Title: *OpenDXM GlobalX - Collaboration with External Partners*	
Description:	OpenDXM is a tool for automating exchange of Digital Data Packages (DDP) between partners. This supports context-based exports for native CAD and product data for engineering and manufacturing, including release data and change management for CAD modifications Corporate partners require continuous, secure exchange of engineering and manufacturing data. Automation built on business processes enables the correct data, with the correct maturity, in the correct formats to be available in near real time between collaborative partners. The demonstrated example is using Teamcenter and CATIA and NX, automate the process of collecting the data, validating it, transforming it, and transferring to the partner Suppliers may require product data for quote, design context, production, and more; customers require delivery and integration of product and design data into the end product.
Goal:	End-to-End integrated product data exchange; provide automation of partner data exchange and transformation between various vendor software solutions

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Data:	CAD, PLM
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	Designer, Systems Engineer, Manufacturing Engineer
Preconditions:	Data is available in source PLM
Postconditions:	Data is made available to the partner, or there is an automated integration process in the partner's data management solution

Notes:



↑ View Digital Twin List ↑ View Digital Thread List

UCDtw030: Model-Based Systems Engineering (MBSE) and Digital Twin Realization of the C-Pulse Drone

USE CASE NUMBER: UCDtw030	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: Capgemini	**Associated Use Cases:**
Use Case Title: *Model-Based Systems Engineering (MBSE) and Digital Twin Realization of the C-Pulse Drone*	
Description:	The C.PULSE Drone project demonstrates capabilities in the field of digital twin and digital thread (continuity) with a pivotal role played by Model-Based Systems Engineering (MBSE); The project comprises the following five facets (Figure 1): MBSE, Design, Hardware, Virtual Reality (VR), and Simulation C.PULSE showcases the integration of different technologies, such as Physics Simulations, Virtual and Augmented Reality (VR/AR), as well the enablement of real-time data exchange, leading to a digital twin realization that facilitates early validation and verification (V&V)
Goal:	1. Demonstrate rapid product development; concept to 3D printed prototype and its V&V within four months 2. Early stakeholder acceptance using digital twin and 3D printed prototype implementation 3. Pivot the overall development around the MBSE model with the MBSE model playing a critical role in driving both hardware in the loop (HIL) and software in the loop (SIL) implementation 4. Rapid and early V&V of concepts and design using the digital twin and 3D Printed prototype; this part will be demonstrated (see Figures 2, 3, 4, 16, 21, and 23 in Notes for implementation details)
Data:	See Notes for detailed description and figures
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☒ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	The use case impacts the following roles at different levels of the hierarchy: (Model-based) Systems Engineers, Digital Twin Specialist, Software Engineers, V&V Engineers, Process Engineer, Design Engineer, Robotics Design Engineers, Robotics Integration Engineer, Electrical and Electronics Engineers, Mechanical Engineers

↑ View Digital Twin List ↑ View Digital Thread List

Preconditions:	• OEM, supplier, or integrator decides to develop, partially or fully, a new system or to upgrade and update a legacy system using MBSE in a digital environment (e.g., aerospace, medical systems, automotive systems, defense systems, drones, etc.) • Principles apply to the organizational upgrade from a document-centric to a completely model-based approach of design and development • Necessary information technology (IT) and automation infrastructure required is available • Access to documentation and basic engineering from the OEM, integrator, and/or supplier can be provided within the context of the project
Special Requirements:	• Enabling digital twin to use MBSE as a source of authority/truth • Interdisciplinary collaboration between different engineering disciplines • Early V&V using digital twin implementation • HIL and SIL testing using early prototyping • Use of AR and VR for early concept validation and stakeholder acceptance • Demonstration of digital continuity and digital thread in the development environment • Use of out-of-the-box (OOTB) solution with minimal to no customization • Demonstrate digital traceability from engineering (Concept) to manufacturing and later lifecycle stages of the system until sunset
Postconditions:	Digital twin of a drone and the physical 3D printed scaled-down prototype of the drone integrated in the loop with the MBSE model Tools and infrastructure required for digital continuity that includes tool selection, integration, and interoperability
Digital Twin Utilization	
Postconditions:	It is recommended to update and maintain the solution throughout the lifecycle of the system to enforce congruency between the virtual and physical system and enforce its usability
Notes:	The demonstration covers the result of digital twin implementation and early prototyping of the C.Pulse drone

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Action (steps in this demonstration)	Result (what to expect from the demonstration and presentation)
1. Presentation and story line recap	A recap of the presentation and the story and approach behind the C.Pulse drone
2. Set up tools for HIL testing	Display the tools used and their integration for the HIL setup (Figures 3 and 4): Power on the drone hardware (HW) Launch the following applications: Mission Planner, Spyder Python API, and Cameo Systems Modeler
3. Establish connection of different elements in the HIL setup	Establish connection between Mission Planner and the drone Run the Python API to establish connection between Cameo and the Mission Planner Execute the MBSE model in Cameo to launch the user interface (Figure 16)
4. Perform early verification of the system behavior using the executable MBSE model	Using the user interface in Cameo, perform a system check of the drone. After the system check passes, arm the drone, takeoff and perform certain maneuvers to test the system behavior; land the drone, and disarm it to end the scenario *All operations triggered from the MBSE model can be observed on the physical prototype of the drone*
5. Set up tools for digital twin and SIL testing	Display the tools used and their integration for the SIL setup (Figure 2): Launch the following applications: Coppelia Sim, Mission Planner, Spyder Python application programming interface (API), and Cameo Systems Modeler
6. Establish connection of different application in the SIL setup	Run the mission planner application and open the User Datagram Protocol (UDP) port of communication Run the Coppelia Sim physics simulation and run the test scene with the Drone (Figure 21) Run the Python API to establish connection between Cameo, Coppelia Sim, and Mission Planner Execute the MBSE model in Cameo to launch the user interface (UI) (Figure 16)

↑ **View Digital Twin List** ↑ **View Digital Thread List**

7. Perform early verification of the system behavior using the executable MBSE model and the digital twin of the system	Using the Cameo user interface, perform a system check of the drone After the system check passes, arm the drone, take off, and perform certain maneuvers to test the system's behavior; land the drone, and disarm it to end the scenario
Note: The MBSE model with both digital twin and hardware can be executed simultaneously as shown in Figure 26, but this has been split into two parts for ease of the demonstration To demonstrate the concept of V&V using AR and VR, headsets are required; this part of the digital twin implementation has been left out of this demonstration; videos of the AR and VR have been shown during the presentation	

If the customer does not need an advanced VR and AR environment because of the type of system, the development process can be descoped, and a minimal solution with only the physics simulation can be developed

A detailed summary with screenshots of the different stages of development has been provided below.

System Overview

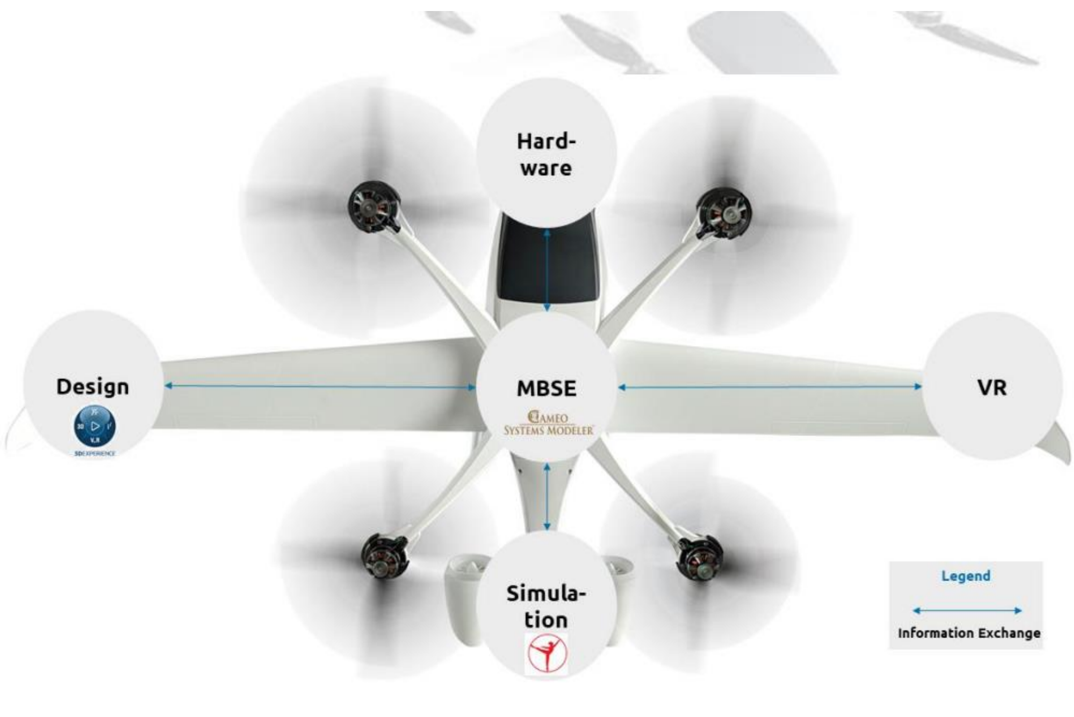


Figure 1.3 System Overview.

Figure 1 - The Five Facets of a C.PULSE project: MBSE, Design, Hardware, VR, and Simulation

Demo Overview

1. Motivation of why C-Pulse

   The COVID-19 pandemic exposed significant vulnerabilities in global healthcare delivery systems. Traditional transportation methods for medical supplies and organs faced numerous challenges, including delays, limited accessibility, and increased risk of contamination. During the pandemic, the need for rapid and safe delivery of medical supplies became even more critical, as healthcare systems were overwhelmed, and resources were stretched thin.

2. Technology setup

   MBSE has been used as a pivot and foundation for systems engineering and system development and realization.

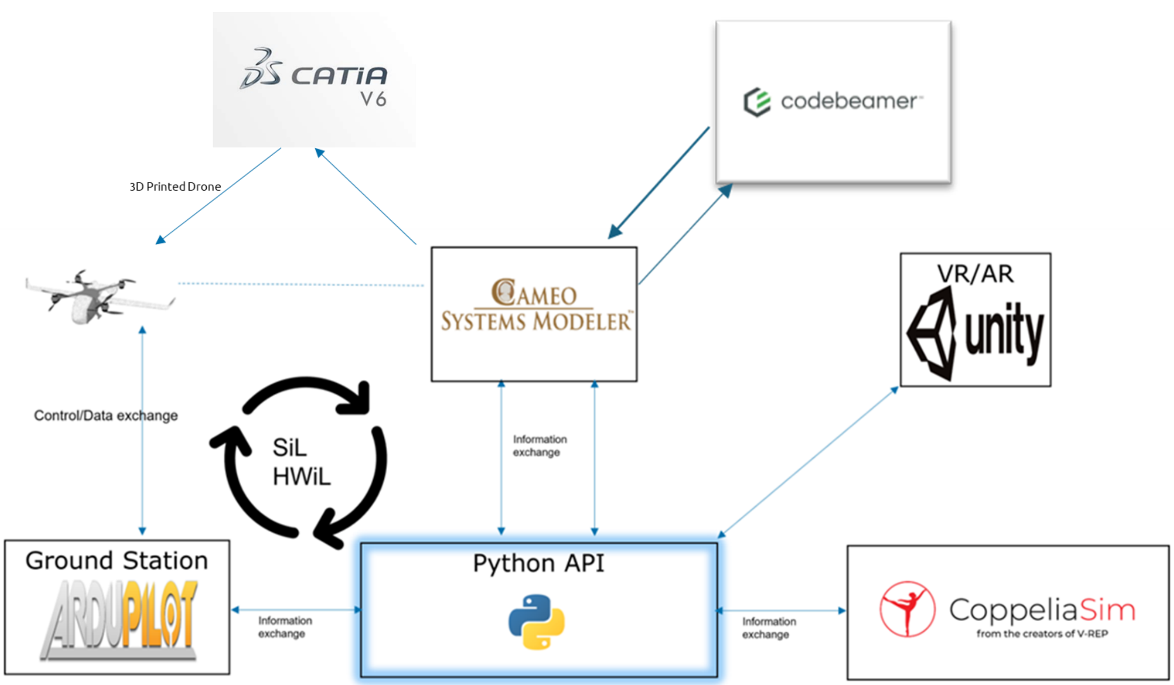


Figure 2 - Tool Setup

↑ View Digital Twin List ↑ View Digital Thread List

The following illustration shows the HIL implementation where the simulation was integrated with a scaled prototype of the drone to facilitate early V&V.

Figure 3 - Reading Telemetry Data from C.PULSE

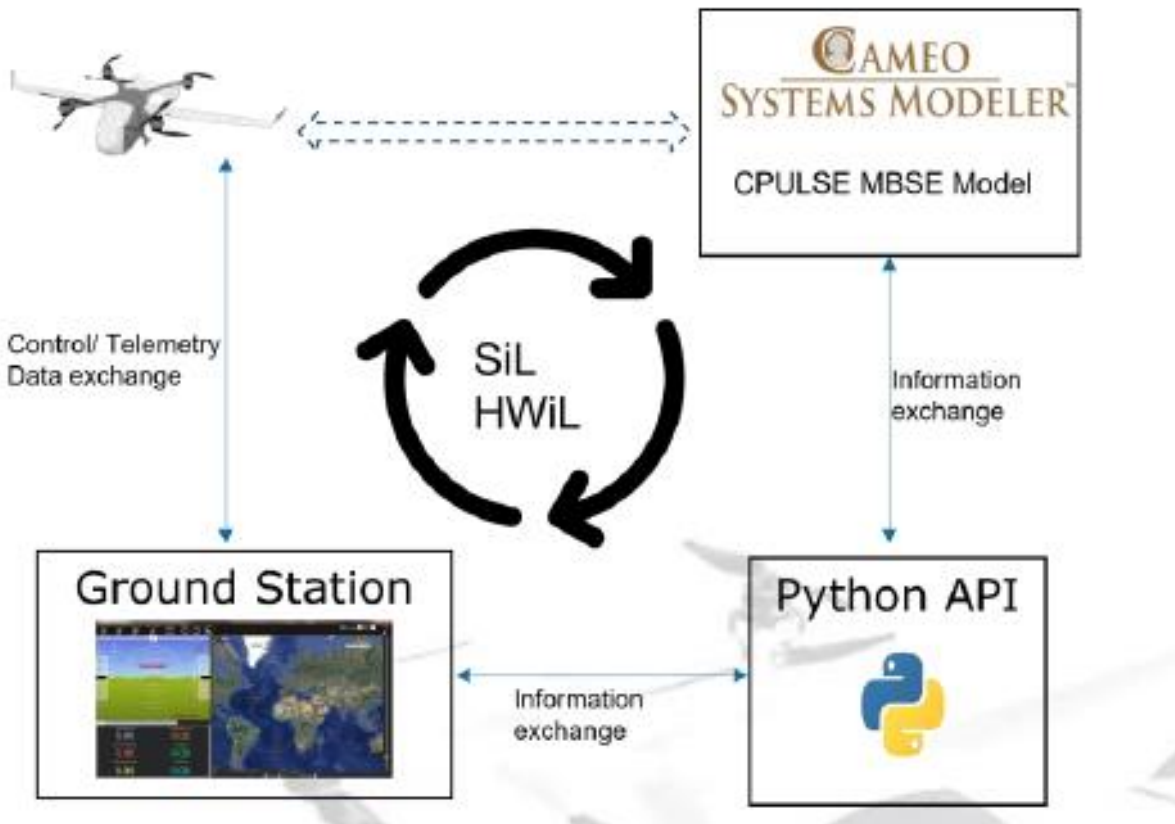


Figure 4 - HIL Implementation

3. BOM

After the MBSE design of the Drone and early V&V of the requirements a detailed analysis and tradeoff is performed to finalize the Make or Buy decision. A sample of the BOM for list of items to buy is shown below (documentation and BOM in Codebeamer).

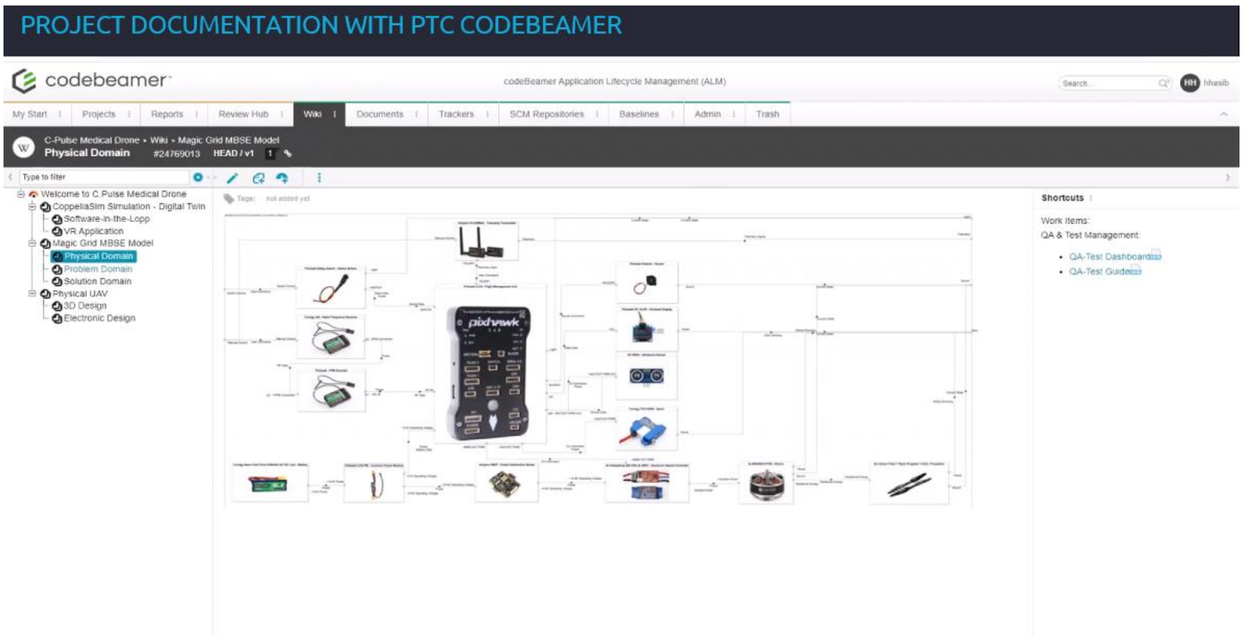


Figure 5 - Documentation in Codebeamer

To-Order Components for CPULSE			**Stand:**	**2/24/2025**		
Classification	**Elementary Component**	**Elementary Component Variant**	**Quantity**	**Price / Unit**	**Total Price**	**Links**
Electronics	micro USB extension	LogiLink CU0120 USB 2.0 Micro-B Power Extension 0,5m	1	6.16 €	6.16 €	https://www.amazon.de/-/en/LogiLink-CU0120-Micro-
Electronics	Miro USB to USB A	USB 2.0 High Speed Data Cable, 5 Pins, 2 x Shielded, AWG28, Colour: Black, Length	1	1.38 €	1.38 €	https://www.amazon.de/-/en/PremiumCord-USB-Con
Electronics	Rotor Motor	T-Motor MN3508-16, 700KV	8	65.39	523.12 €	https://store.tmotor.com/goods.php?id=356
Electronics	Speed Controller	HobbyKing 30A (2~4S) ESC 3A UBEC	8	13.74	109.92 €	https://hobbyking.com/en_us/hobbyking-30a-2-4s-esc
Electronics	Battery	Turnigy Nano-Tech Plus 5200mAh 4S 70C Lipo Pack w/XT90	2	90.45	180.90 €	https://hobbyking.com/en_us/turnigy-nano-tech-pl
Electronics	Battery Charger	Turnigy Accucell C150 AC/DC 10A 150W Smart Balance Charger (US Plug)	1	125.19	125.19 €	https://hobbyking.com/en_us/isdt-k1-dual-port-1-6s-1
Electronics	RC Controller	Turnigy TGY-i6 Mode 2 AFHDS Transmitter and 6CH Receiver	1	64.38 €	64.38 €	https://hobbyking.com/en_us/turnigy-tgy-i6-mode-2-a
Electronics	Flight Controller	Pixhawk 2.5.8 (with peripheral accessories)	1	280	280.00 €	
Electronics	Power Management Module for Pixhawk	HolyBro PM07 Power Management PM Modul mit 5V UBEC Ausgang für Pixhawk 4 P	1	60	60.00 €	https://www.mybotshop.de/Pixhawk-PX4-Power-Mod
Electronics	Arduino	Ardunio UNO	1	20	20.00 €	
Electronics	Servo Motors	Servo Motors for the Opening Mechanism	1	48.60 €	48.60 €	https://www.amazon.de/-/en/RC-Servo-Digital-Steerin
Electronics	Programmable LED Strips	RGB LED Flexible Strip with 4-pin Driver Connector 1m (Red/Green/Blue)	1		0.00 €	
Electronics	Jumpers	Jumpers wires	1		0.00 €	
Electronics	Connectors	XT90 Female Connector w/100mm Red/Black Wire (2pcs)	1		0.00 €	
Electronics	Connectors 1	Female Bullet Connectors 3.5 mm	1	5	5.00 €	https://extron.pichler.de/Go https://hobbyking.com htt
Electronics	Connectors 2	Nylon XT90 Connectors Male / Female With End Cap (5 Sets) Yellow	1	5	5.00 €	https://hobbyking.com/en_us/xt90-female-connector-
Electronics	XT60 Female/male	XT60plus with Insulating End Cap (Male & Female) (5set/bag)	2	6.22 €	12.44 €	https://hobbyking.com/en_us/new-xt60plus-with-insu
Electronics	Telemetry	Telemetry Radio Set V3 433MHz 100mW	1	119.95 €	119.95 €	https://www.mybotshop.de/Telemetry-Radio-Set-V3-4
Electronics	Wires	18 AWG Wires: Red and Black	2	11.00 €	22.00 €	https://hobbyking.com/en https://hobbyking.com/en
Electronics	Battery Charger Connector	XT90 male to XT60 female 2pcs/bag	4	4.00 €	16.00 €	https://hobbyking.com/en_us/xt90-male-to-xt60-fema
Electronics	Battery wire extension	10 AWG wire	1	3.97 €	3.97 €	https://hobbyking.com/en_us/turnigy-high-quality-10
Electronics	Batery eliminator circuit (12V supply to	Turnigy Multistar Twin Output 5/10 Amp (6-50V) SBEC for Lipoly	1	27.12 €	27.12 €	https://hobbyking.com/en_us/turnigy-multistar-twin-
Electronics	wire for LED	22 awg with connectors	1	7.29 €	7.29 €	https://www.amazon.de/ikarex-shop-Stecker-Buchse-
Electronics	extension wire	Fermerry 26 AWG Stranded Wire Silicone Tinned Copper Wire Spool 0.15 mm² Each	1	15.99 €	15.99 €	https://www.amazon.de/Fermerry-Stranded-Silicone-
Electronics	Resistor for LED	470 ohm	1	1.39 €	1.39 €	https://www.amazon.de/Kohleschicht-Widerstand-Res
Electronics	Battery voltage tester	[illegible]	1	6.39 €	6.39 €	https://www.amazon.de/-/en/DollaTek-Battery-Monit
Hardware	Propellers	Quanum Carbon Fiber T-Style Propeller 11x5.5 (CW/CCW) (2pcs)	8	11.25	90.00 €	https://hobbyking.com/en_us/quanum-carbon-fiber-t-
Hardware	LiPo Bag	Turnigy® Fire Retardant LiPoly Battery Bag (190x68x50mm) (1pc)	1	2.87	2.87 €	https://hobbyking.com/en_us/fire-retardan
Hardware	Battery Straps	Turnigy 400mm Battery Strap (3pcs)	1	4.63	4.63 €	https://hobbyking.com/en_us/turnigy-400n
Hardware	Heat Shrink	Heat Shrink	1	7.33 €	7.33 €	https://hobbyking.com/en_us/heat-shrink-tubing-tube
Hardware	Carbon Fiber Tubes	Carbon Fiber Tube for the Fuselage Wings Assembly	1	12.00 €	12.00 €	https://www.conrad.de/de com/web/p/kunststo co
Hardware	Servo horn extension 1	CNC Alloy Servo Arm Long (Futaba)	1	4.97 €	4.97 €	https://hobbyking.com/en_us/cnc-alloy-servo-arm-lon
Hardware	Servo horn extension 2	Absima aluminum servo arm	1	10.88 €	10.88 €	https://www.conrad.de/de/p/absima-alu-servohebel-
Hardware	Linkage connector	Reely linkage connection bore diameter: 2 mm 10 pcs.	1	9.20 €	9.20 €	https://www.conrad.de/de/p/reely-gestaengeanschlus
Hardware	M3 screws	Sortiment-Zylinderschrauben mit Innensechskant DIN 912 M3	1	18.95 €	18.95 €	https://www.schrauben-guenstiger.de/Schrauben/Inb
Hardware	M4 screws	Sortiment-Zylinderschrauben mit Innensechskant DIN 912 M4 Edelstahl 440 Teile	1	18.95 €	18.95 €	https://www.schrauben-guenstiger.de/advanced_sear
Hardware	Push rod for door	Reely push rod length: 200 mm outer diameter: 2 mm 1 pc.	1	1.64 €	1.64 €	https://www.conrad.de/de/p/reely-schubstange-laeng

Figure 6 - Bill of Materials

↑ **View Digital Twin List** ↑ **View Digital Thread List**

4. MBSE model in SysML - the pivot and foundation for systems engineering and system development

Requirements engineering, project management, and final documentation and publishing were performed using PTC Codebeamer.

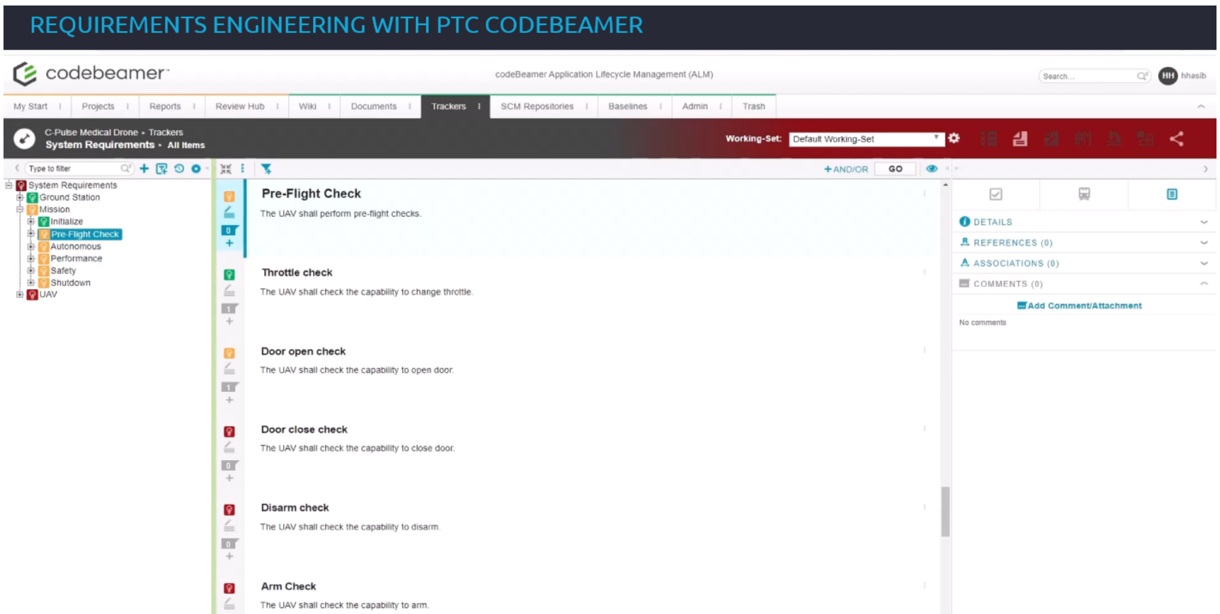


Figure 7 - Requirements Management Using Codebeamer

This next section highlights the Concept design and system architecture of the C.PULSE drone with the MBSE model in Cameo Systems Modeler.

Please note that Cameo/Catia Magic has been used without any customizations. The OOTB Methodology (Magic Grid) and SysML have been used for the design and architecture of the Drone.

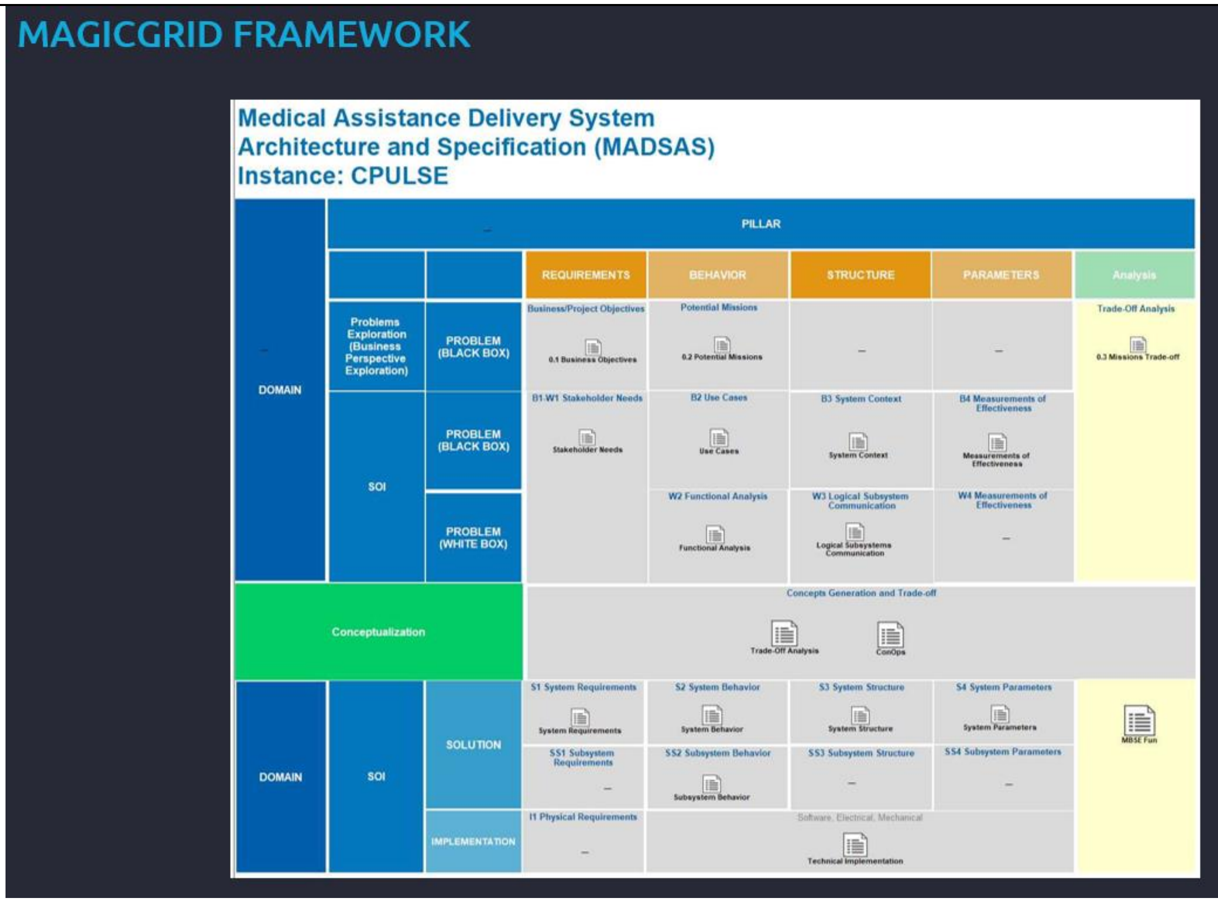


Figure 8 - MagicGrid Framework

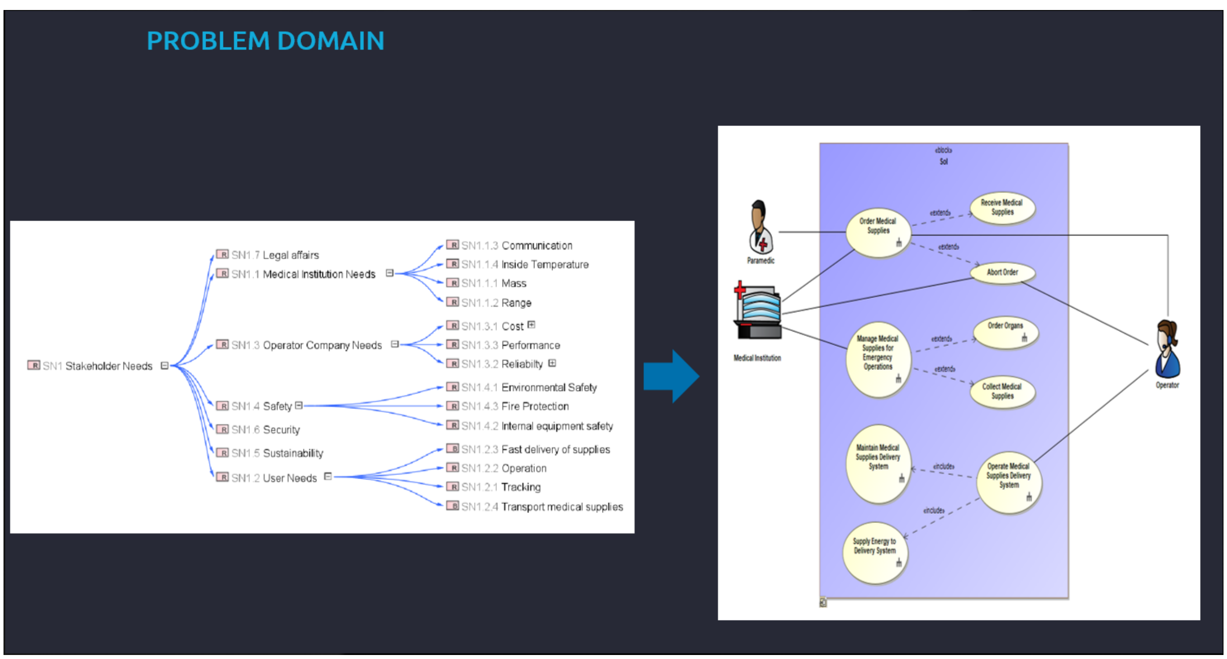


Figure 9 - Problem Domain

↑ View Digital Twin List ↑ View Digital Thread List

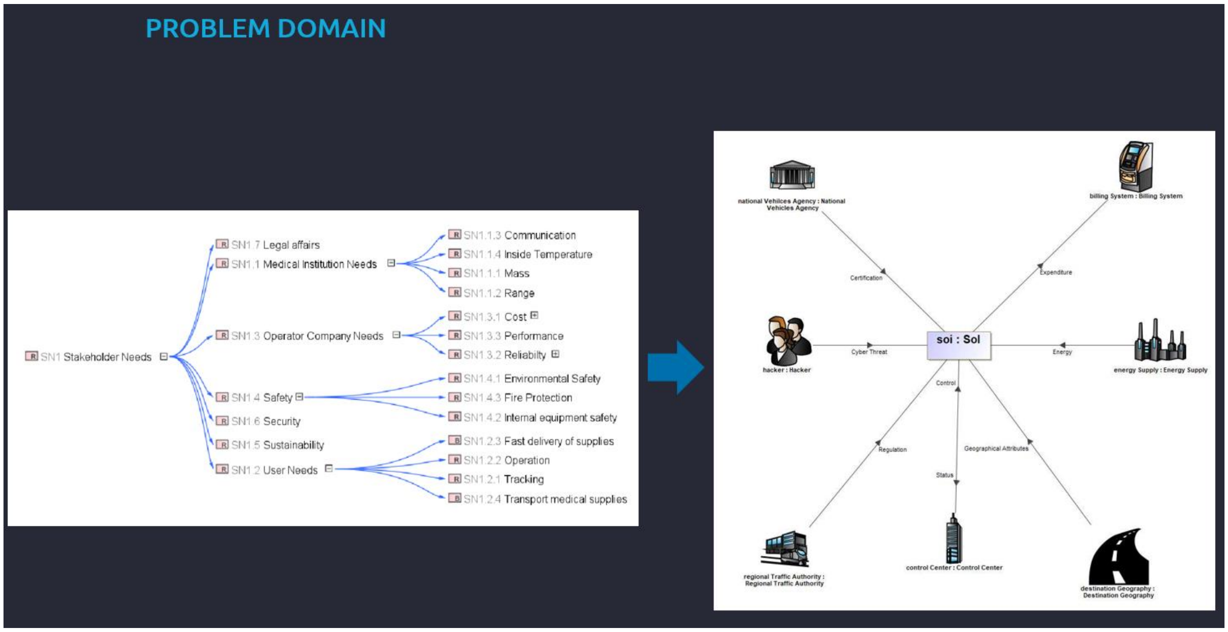


Figure 10 - System Context

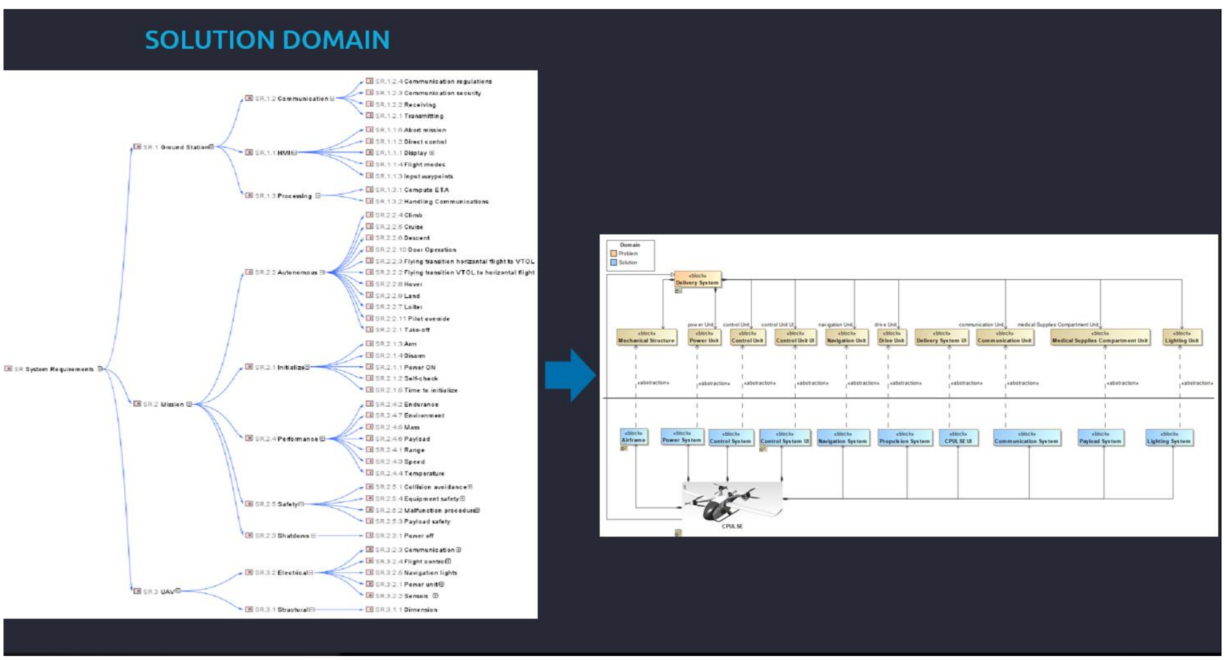


Figure 11 - Logical to Physical System Decomposition

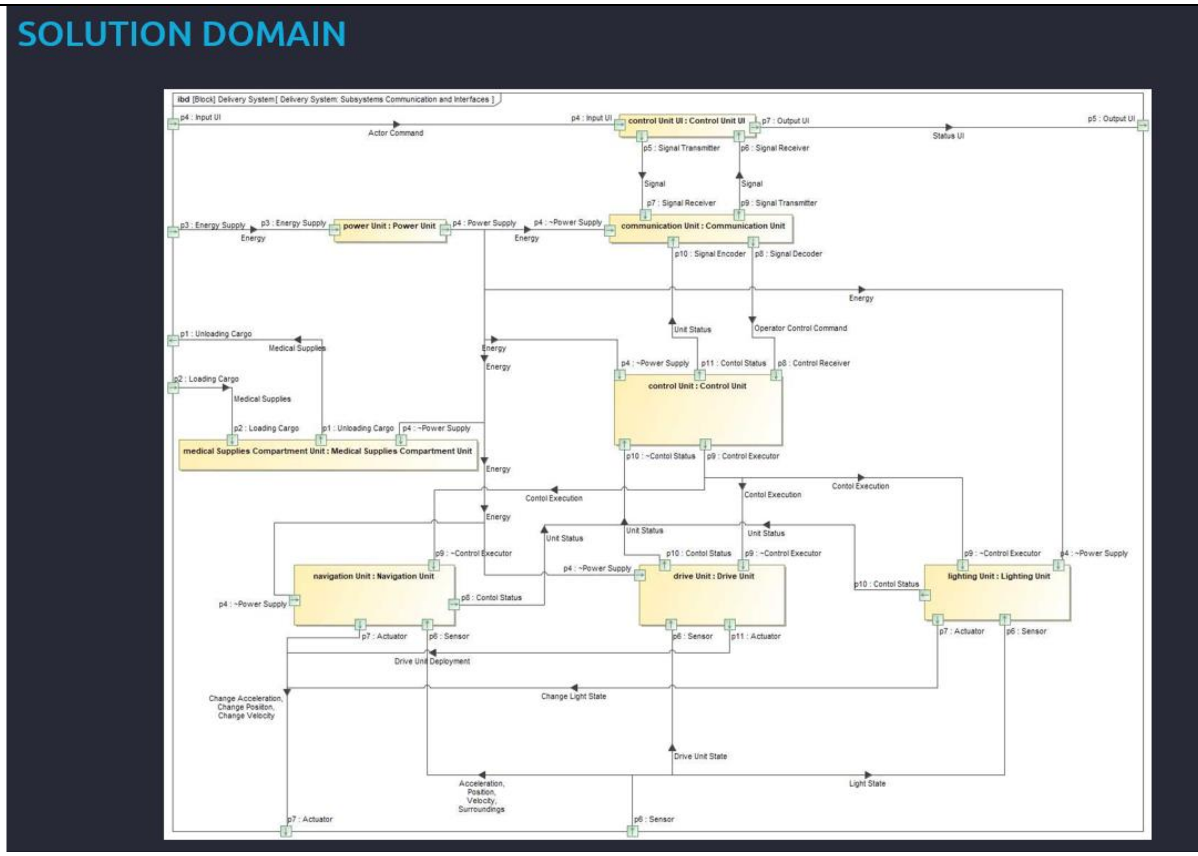


Figure 12 - Solution Domain

#	Part A	Port A	Port A Features	Item Flow	Port B	Port B Features	Part B
1	communication Unit: Communic...	out p8 : Signal Decoder	out OCC : Operator Control Comm	▶ Operator Control Command	in p8 : Control Receiver	in OCC : Operator Control Comma	control Unit : Control Unit
2	communication Unit: Communic...	out p9 : Signal Transmitter	out S : Signal	▶ Signal	in p6 : Signal Receiver	in S : Signal	control Unit UI : Control Unit UI
3	control Unit UI : Control Unit UI	out p5 : Signal Transmitter	out S : Signal	▶ Signal	in p7 : Signal Receiver	in S : Signal	communication Unit: Communic...
4	control Unit UI : Control Unit UI	out p7 : Output UI	out Stat_UI : Status UI	▶ Status UI	out p5 : Output UI	out Stat_UI : Status UI	Delivery System
5	control Unit : Control Unit	out p9 : Control Executor	out CE : Contol Execution	▶ Contol Execution	in p9 : ~Control Executor	in CE : Contol Execution	drive Unit : Drive Unit
6	control Unit : Control Unit	out p9 : Control Executor	out CE : Contol Execution	▶ Contol Execution	in p9 : ~Control Executor	in CE : Contol Execution	lighting Unit: Lighting Unit
7	control Unit : Control Unit	out p9 : Control Executor	out CE : Contol Execution	▶ Contol Execution	in p9 : ~Control Executor	in CE : Contol Execution	navigation Unit : Navigation Unit
8	control Unit : Control Unit	out p11 : Contol Status	out US : Unit Status	▶ Unit Status	in p10 : Signal Encoder	in US : Unit Status	communication Unit: Communic...
9	drive Unit : Drive Unit	out p10 : Contol Status	out US : Unit Status	▶ Unit Status	in p10 : ~Contol Status	in US : Unit Status	control Unit : Control Unit
10	drive Unit : Drive Unit	out p11 : Actuator	out Ch_Acc : Change Acceleration out Ch_LS : Change Light State out Ch_Pos : Change Posiiton out Ch_V : Change Velocity out DU_D : Drive Unit Deployment	▶ Drive Unit Deployment	out p7 : Actuator	out Ch_Acc : Change Acceleration out Ch_LS : Change Light State out Ch_Pos : Change Posiiton out Ch_V : Change Velocity out DU_D : Drive Unit Deployment	Delivery System
11	lighting Unit: Lighting Unit	out p7 : Actuator	out Ch_Acc : Change Acceleration out Ch_LS : Change Light State out Ch_Pos : Change Posiiton out Ch_V : Change Velocity out DU_D : Drive Unit Deployment	▶ Change Light State	out p7 : Actuator	out Ch_Acc : Change Acceleration out Ch_LS : Change Light State out Ch_Pos : Change Posiiton out Ch_V : Change Velocity out DU_D : Drive Unit Deployment	Delivery System
12	lighting Unit: Lighting Unit	out p10 : Contol Status	out US : Unit Status	▶ Unit Status	in p10 : ~Contol Status	in US : Unit Status	control Unit : Control Unit
13	navigation Unit : Navigation Unit	out p7 : Actuator	out Ch_Acc : Change Acceleration out Ch_LS : Change Light State out Ch_Pos : Change Posiiton out Ch_V : Change Velocity out DU_D : Drive Unit Deployment	▶ Change Acceleration ▶ Change Posiiton ▶ Change Velocity	out p7 : Actuator	out Ch_Acc : Change Acceleration out Ch_LS : Change Light State out Ch_Pos : Change Posiiton out Ch_V : Change Velocity out DU_D : Drive Unit Deployment	Delivery System
14	navigation Unit : Navigation Unit	out p8 : Contol Status	out US : Unit Status	▶ Unit Status	in p10 : ~Contol Status	in US : Unit Status	control Unit : Control Unit
15	Delivery System	out p1 : Unloading Cargo	out MS	◀ Medical Supplies	out p1 : Unloading Cargo	out MS	medical Supplies Compartment ...
16	Delivery System	in p2 : Loading Cargo	in MS	▶ Medical Supplies	in p2 : Loading Cargo	in MS	medical Supplies Compartment ...
17	Delivery System	in p3 : Energy Supply	in E : Energy	▶ Energy	in p3 : Energy Supply	in E : Energy	power Unit : Power Unit
18	Delivery System	in p4 : Input UI	in A_Cmd : Actor Command	▶ Actor Command	in p4 : Input UI	in A_Cmd : Actor Command	control Unit UI : Control Unit UI
19	Delivery System	in p6 : Sensor	in Acc : Acceleration in DUS : Drive Unit State in LS : Light State in Pos : Position in Sur : Surroundings in V : Velocity	▶ Drive Unit State	in p6 : Sensor	in Acc : Acceleration in DUS : Drive Unit State in LS : Light State in Pos : Position in Sur : Surroundings in V : Velocity	drive Unit : Drive Unit
20	Delivery System	in p6 : Sensor	in Acc : Acceleration in DUS : Drive Unit State in LS : Light State in Pos : Position in Sur : Surroundings in V : Velocity	▶ Light State	in p6 : Sensor	in Acc : Acceleration in DUS : Drive Unit State in LS : Light State in Pos : Position in Sur : Surroundings in V : Velocity	lighting Unit: Lighting Unit
21	Delivery System	in p6 : Sensor	in Acc : Acceleration in DUS : Drive Unit State in LS : Light State in Pos : Position in Sur : Surroundings in V : Velocity	▶ Acceleration ▶ Position ▶ Velocity ▶ Surroundings	in p6 : Sensor	in Acc : Acceleration in DUS : Drive Unit State in LS : Light State in Pos : Position in Sur : Surroundings in V : Velocity	navigation Unit : Navigation Unit
22	power Unit : Power Unit	out p4 : Power Supply	out E : Energy	▶ Energy	in p4 : ~Power Supply	in E : Energy	communication Unit: Communic...
23	power Unit : Power Unit	out p4 : Power Supply	out E : Energy	▶ Energy	in p4 : ~Power Supply	in E : Energy	control Unit : Control Unit
24	power Unit : Power Unit	out p4 : Power Supply	out E : Energy	▶ Energy	in p4 : ~Power Supply	in E : Energy	drive Unit : Drive Unit
25	power Unit : Power Unit	out p4 : Power Supply	out E : Energy	▶ Energy	in p4 : ~Power Supply	in E : Energy	lighting Unit: Lighting Unit
26	power Unit : Power Unit	out p4 : Power Supply	out E : Energy	▶ Energy	in p4 : ~Power Supply	in E : Energy	medical Supplies Compartment ...
27	power Unit : Power Unit	out p4 : Power Supply	out E : Energy	▶ Energy	in p4 : ~Power Supply	in E : Energy	navigation Unit : Navigation Unit

Figure 13 - Interface Control

↑ View Digital Twin List ↑ View Digital Thread List

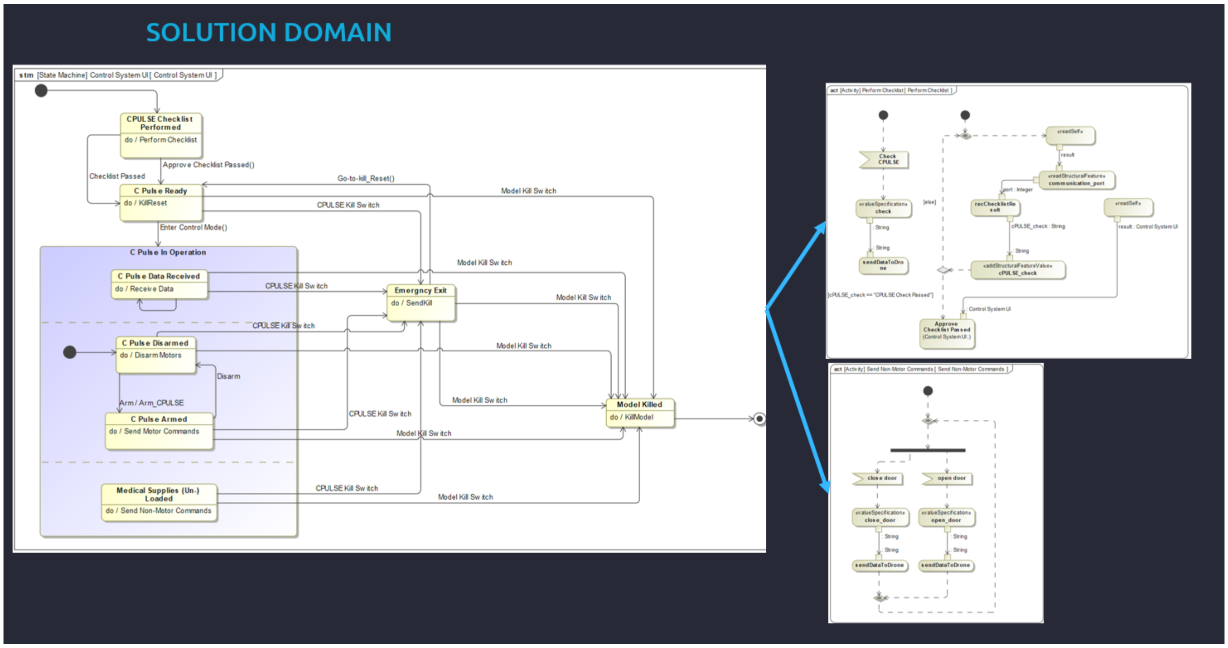


Figure 14 - System Behavior

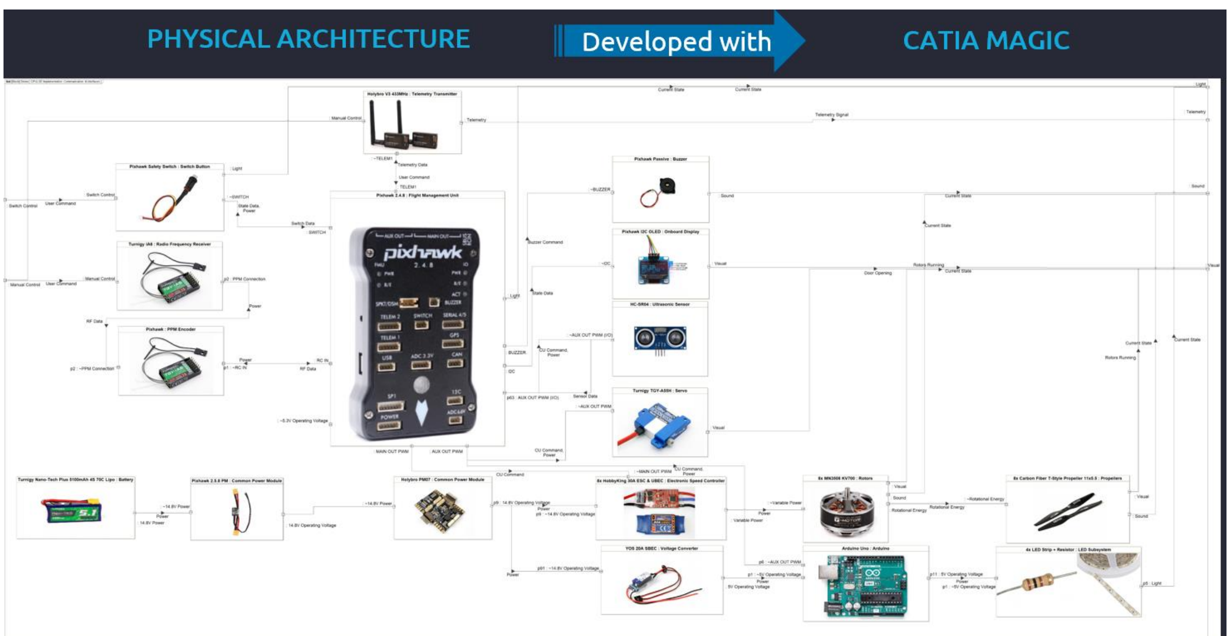


Figure 15 - Physical Architecture of Electronics and Electrical Systems

5. Early verification using Cameo SysML simulation – Stage 1

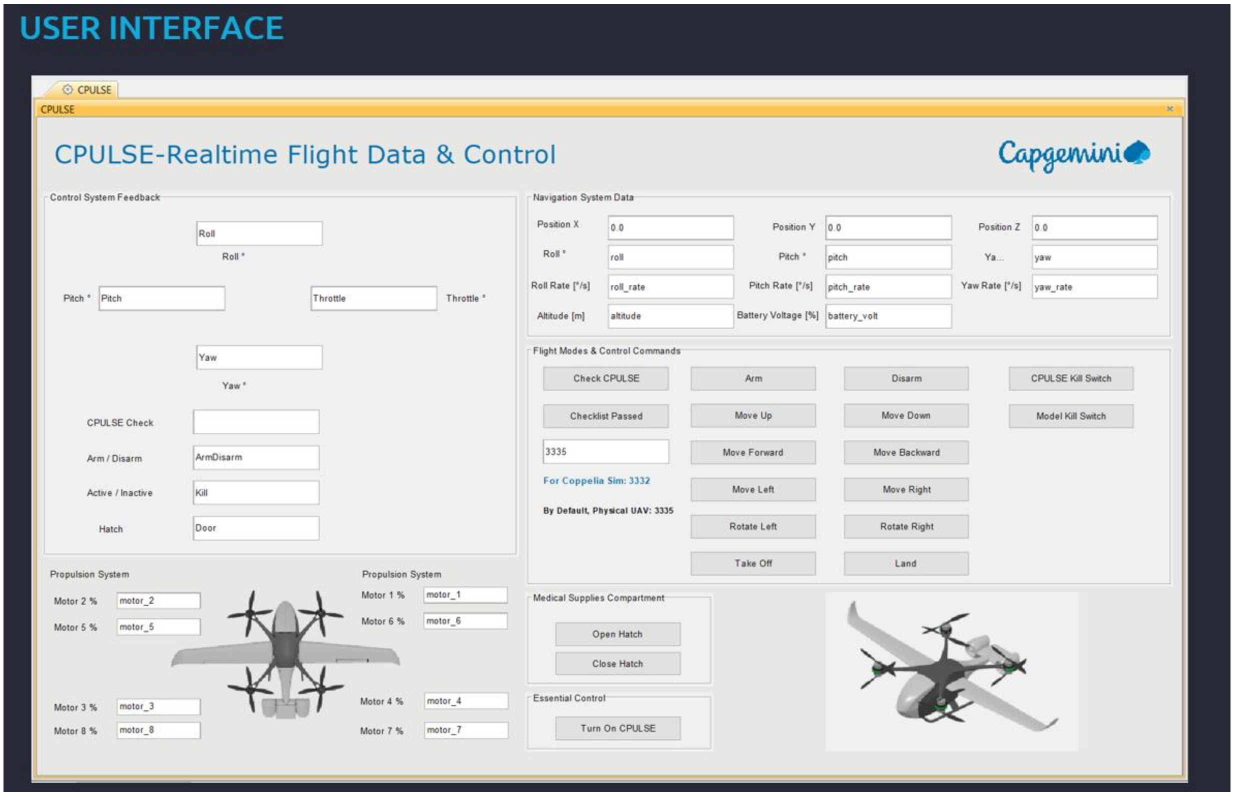


Figure 16 - C.PULSE Graphical User Interface (GUI)

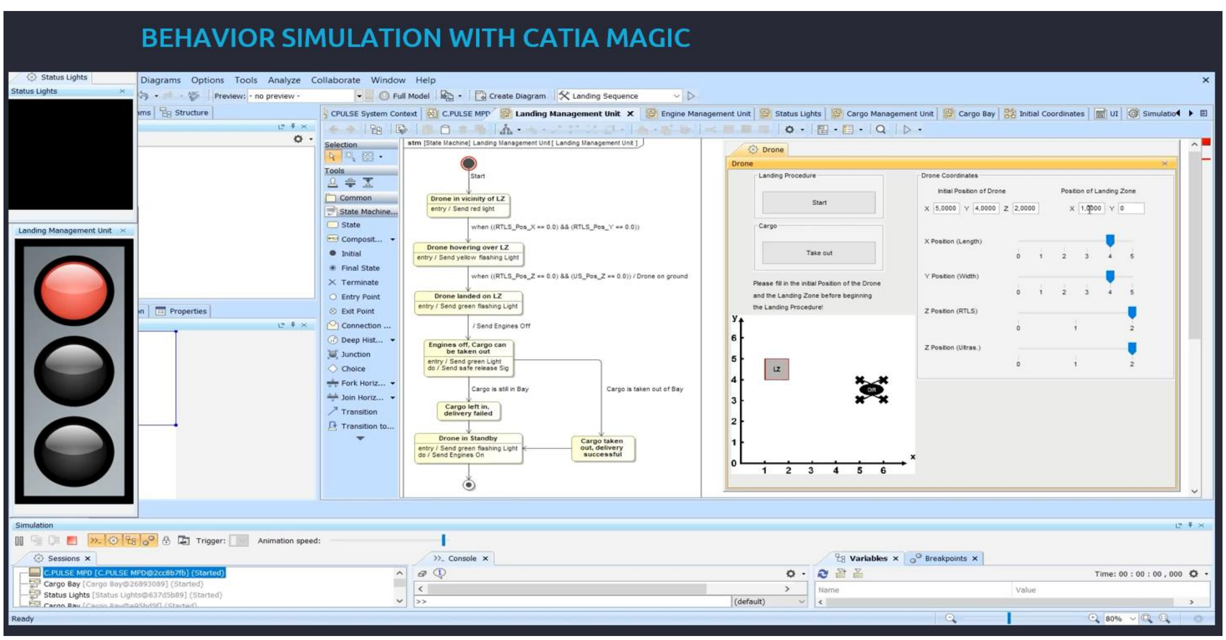


Figure 17 - C.PULSE Behavior Simulation

↑ View Digital Twin List ↑ View Digital Thread List

6. MBSE to MBD transition for the mechanical CAD designs

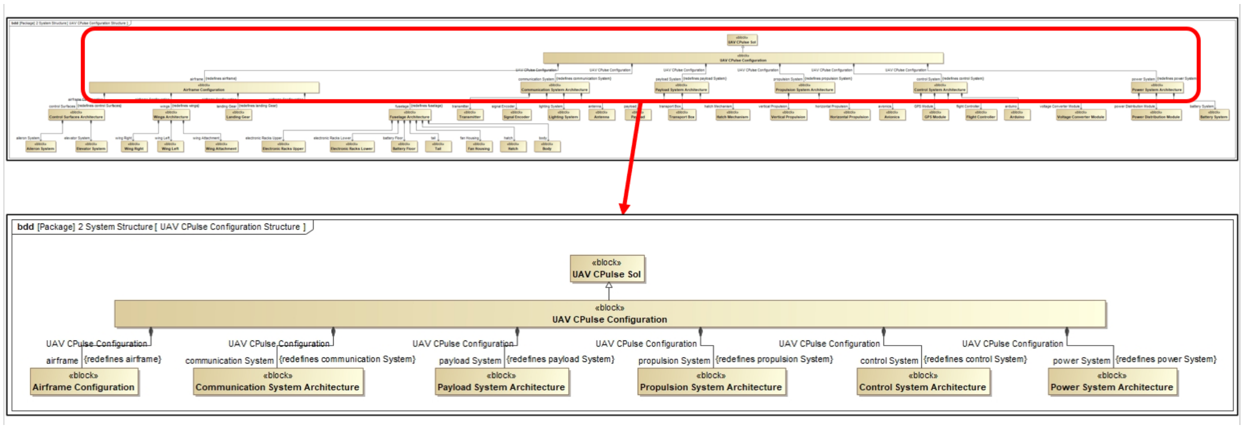


Figure 18 - MBSE to MBD Transition

#	Name	Text
1	SR-1 SRS for UAV CPulse	
2	SR-1.1 UAV CPulse Mass	The UAV CPulse shall not exceed a mass of 63 kg
3	SR-1.2 UAV CPulse Center of Gravity in x Direction	The position of the center of gravity of the UAV CPulse measured according to the global coordinate system shall be between -130 mm and -35 mm in x direction
4	SR-1.3 UAV CPulse Center of Gravity in y Direction	The position of the center of gravity of the UAV CPulse measured according to the global coordinate system shall be between -2.5 mm and 2.5 mm in y direction
5	SR-1.4 UAV CPulse Center of Gravity in z Direction	The position of the center of gravity of the UAV CPulse measured according to the global coordinate system shall be between 585 mm and 590 mm in z direction
6	SR-1.5 UAV CPulse Cost	The 3D printed parts of UAV CPulse shall not exceed a cost of 27000 Euro

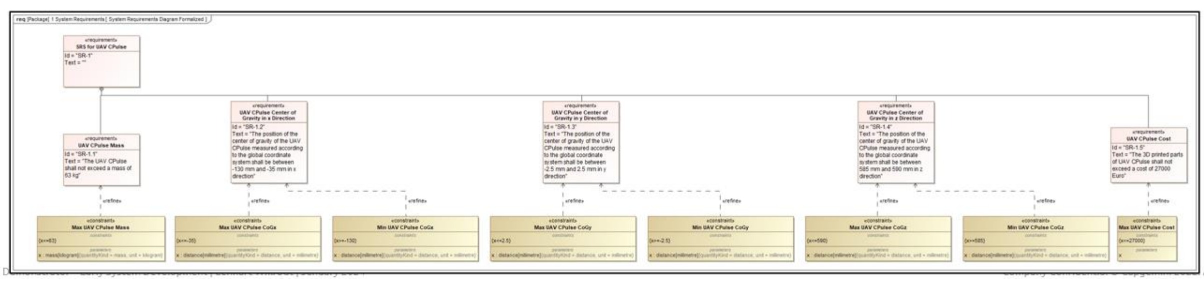


Figure 19 - Physical Requirements

7. AR and VR creation using CAD design

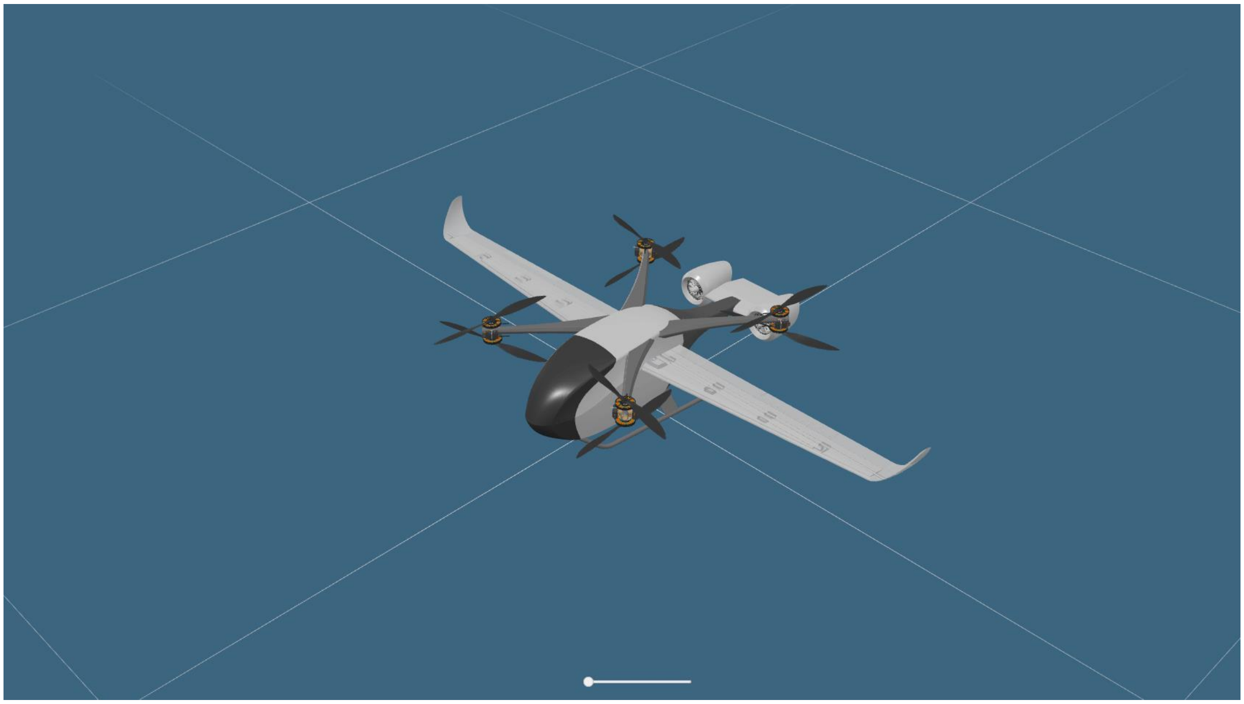


Figure 20 - Drone Assembly

8. Integration of Cameo simulation with Physics, VR and AR simulation

Figure 21 - Physics Simulation Using Coppelia Sim

↑ View Digital Twin List ↑ View Digital Thread List

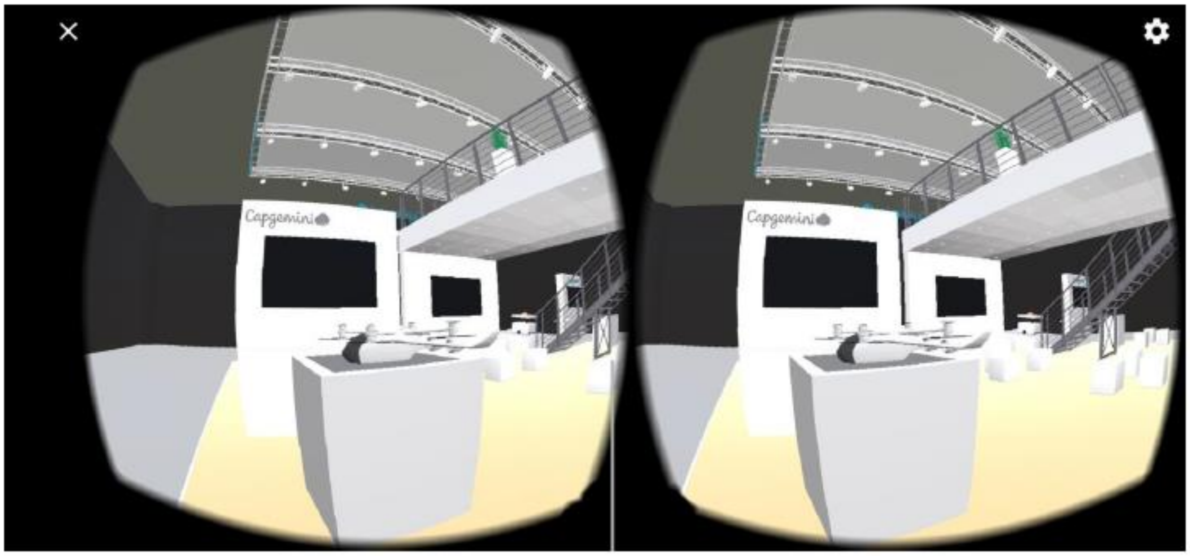


Figure 22 - Integration of VR and AR Simulation

9. Early verification using Cameo SysML simulation in integration with Physics, VR and AR simulation – Stage 2

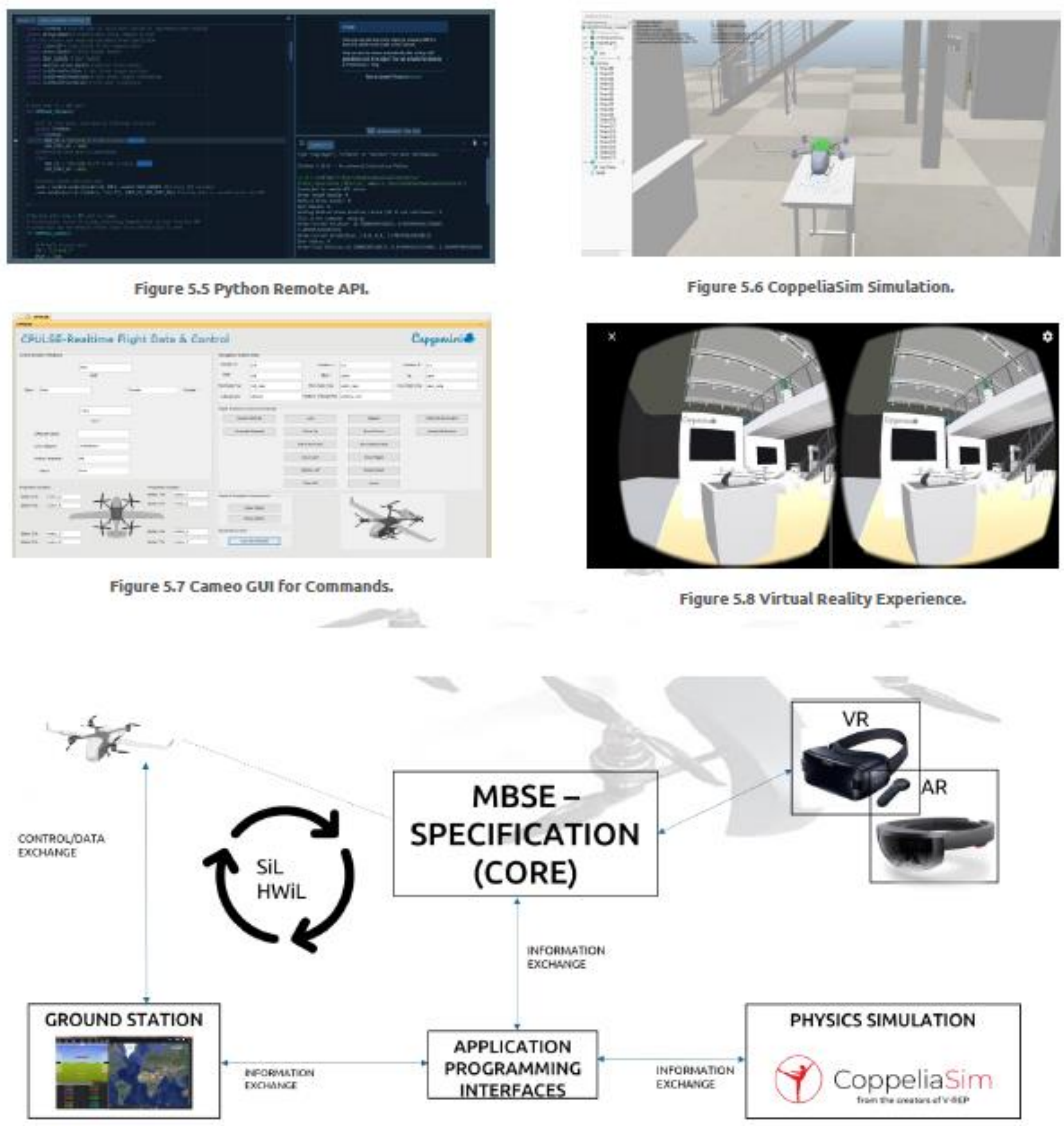


Figure 23 - Early V&V Using Cameo SysML Simulation

↑ [View Digital Twin List](#) ↑ [View Digital Thread List](#)

10. 3D Printing and early prototyping from the CAD design

Figure 24 - 3D Printed Parts

11. Prototype HW integration of mechanical + electrical + electronics and software (SW)

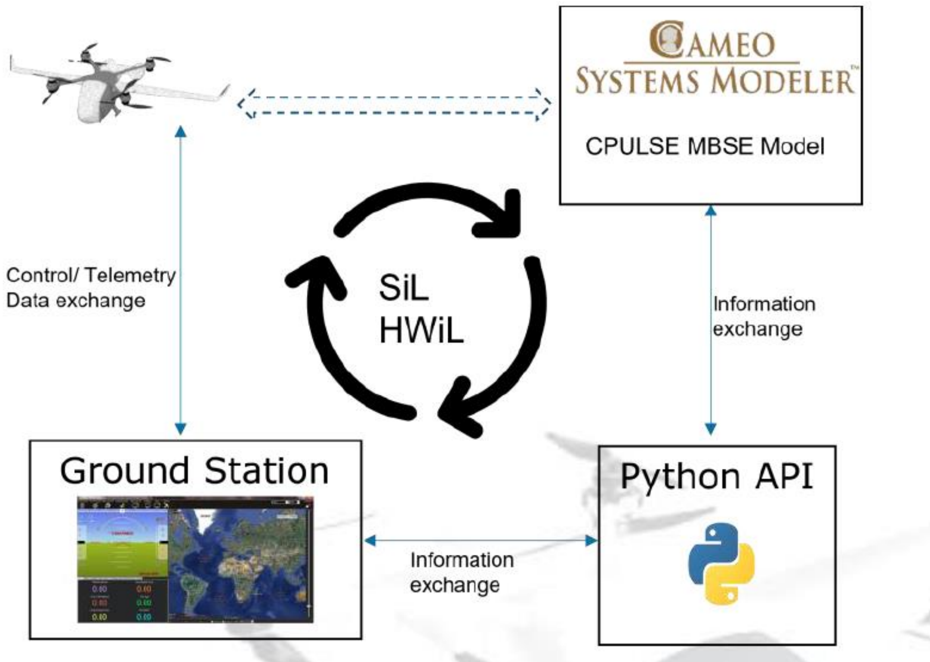


Figure 25 - Flow of Information Between C.PULSE and Cameo

12. Cameo simulation integration with prototype hardware (HW)

Figure 26 - Cameo Simulation Integration with Prototype HW

↑ View Digital Twin List ↑ View Digital Thread List

13. Early verification with HIL testing using Cameo simulation + Physics Simulation + VR and AR simulation + real HW integration – Stage 3

UCDtw031: Virtual Commissioning Automotive Demonstrator for Body-in-White Assembly Process

USE CASE NUMBER: UCDtw031	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: Capgemini	**Associated Use Cases:**
Use *Case Title:* *Virtual Commissioning Automotive Demonstrator for Body-in-White Assembly Process*	
Description:	Showcase with an automotive use case how virtual commissioning solutions can developed and be integrated as part of a digital twin
Goal:	• Reduce time-to-market • Derisk commissioning and production ramp-up through early verification and validation (V&V) • Guarantee a "right first time"
Data:	See the Notes section, which includes content/steps and Figures 1-10
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☒ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	The use case impacts the following roles at different levels of hierarchy: Systems Engineer, Process Engineer, Production Engineer, Design Engineer, Manufacturing J&T Engineers, Automation Engineer, Robotics Design Engineers, Robotics Integration Engineer, Manufacturing System Suppliers, Robotic Systems Supplier
Preconditions:	• OEM, supplier, or integrator decides to automate partially or fully a new production process or to refurbish/renew an existing one (e.g., Jigs/Tools; Positioners; Machines; In Station, Cell, or Line) • The information technology (IT) and automation architecture (concept or final) of the industrial system (i.e., Positioner, machine) is available. • Access to documentation and basic engineering from Original Equipment

↑ View Digital Twin List ↑ View Digital Thread List

	Manufacturer (OEM), integrator, and/or supplier can be provided in context of the project
Special Requirements:	• Enable communication channels to the software or PLM platform vendor and to the Manufacturing System Suppliers and Robotic Systems Supplier • The recommendation is to develop the solutions in the customer PLM platform/IT environment to avoid compatibility and performance issues caused by divergences in customization and versions between developer and end-user environments • Backup of the programmable logic controller (PLC) project—minimum configuration early in the project, optimally the PLC program—and electrical drawings for configuration of virtual commissioning projects and validation of the solution
Postconditions:	• Implement user access control in the virtual commissioning solution for at least two roles: Standard User and Admin • Generate a backup of all operational technology (OT) programs
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☒ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	Systems Engineer, Process Engineer, Production Engineer, Design Engineer, Manufacturing J&T Engineers, Automation Engineer, Robotics Design Engineers, Robotics Integration Engineer, Manufacturing System Suppliers, Robotic Systems Supplier
Preconditions:	• Access to IT resources (i.e., PLM platform, databases integrated development environment (IDE), collaborative spaces) and licenses available • OT programs available, including PLC, human machine interface (HMI), robot programs • For applicable use cases, hardware components available and functional • User access control properly implemented to avoid unwanted or accidental modifications
Special Requirements:	Knowledge in development and validation of OT software (e.g., PLC, HMI, robot programs)
Postconditions:	• Solution must be maintained throughout the lifecycle of the manufacturing system to avoid divergences after updates to the physical system

↑ View Digital Twin List ↑ View Digital Thread List

	• Storage with version control of OT programs is highly recommended to avoid divergences between real and physical system

Notes:

What is Virtual Commissioning?

Virtual commissioning is the use of modelling and simulation technologies to validate software, system functionalities, and upgrades virtually before deploying them to the real production system. Its main benefits are:

- Reduce time-to-market
- Guarantee a “right first time”

Generic Lifecycle of Production Projects

The generic lifecycle of manufacturing and production projects used as a basis is shown below.

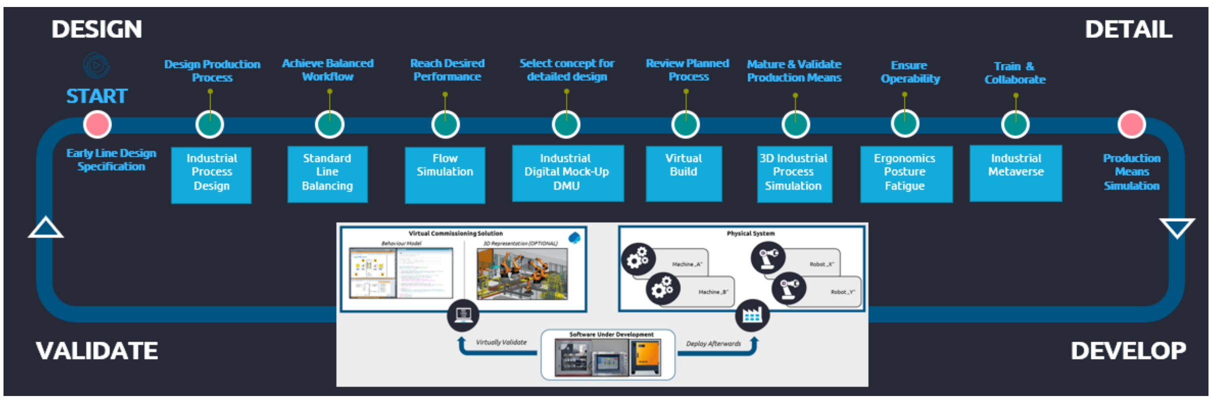


Figure 1 - Typical Project Lifecycle of Industrialization Project

The different stages shown must be synchronized with the milestones defined by the customer’s large industrialization project/initiative.

To produce/manufacture a product, production processes are designed tested for feasibility. The concepts are validated through simulation, to ensure their feasibility and ensure the required throughput can be achieved. Selected concepts and shortlisted further and matured, until a final one is chosen. This concept will be detailed into the final solution. Virtual commissioning starts once a concept has been chosen, the detailed engineering has maturity, and specific milestones gates have been reached–typically around the time automation software development begins.

How Do Virtual Commissioning Solutions Look?

Virtual commissioning solutions are typically composed of the following two parts:

- Functional and behavior models encapsulating the machine’s mechatronic behavior
- 3D-representation of the system

↑ View Digital Twin List ↑ View Digital Thread List

At a minimum, these solutions must be composed of functional and behavior models. The 3D-representation, while optional, provides advanced capabilities, such as clash and collision analysis, human and ergonomic simulation, and Robotics Offline-Programming (OLP) for the solution.

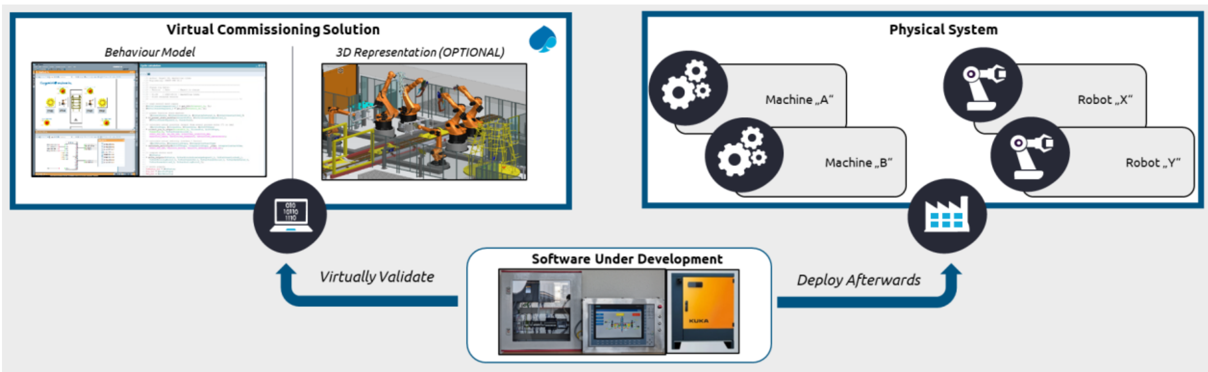


Figure 2 - How Virtual Commissioning is Used in Practice

Automation and production software is connected to the solution and used to incrementally validate the development of software modules and their integration in the final program through simulation. By identifying issues and bugs in the code, developers are allowed to fail fast and solve their program early in the development cycle, minimizing economic impact and reducing risks of delay during the commissioning and production ramp-up.

Virtual Commissioning Framework

In 2019 Capgemini developed a framework for virtual commissioning, which enables the development and delivery of vendor-agnostic solutions with a high level of transparency and predictability through a holistic simulation approach.

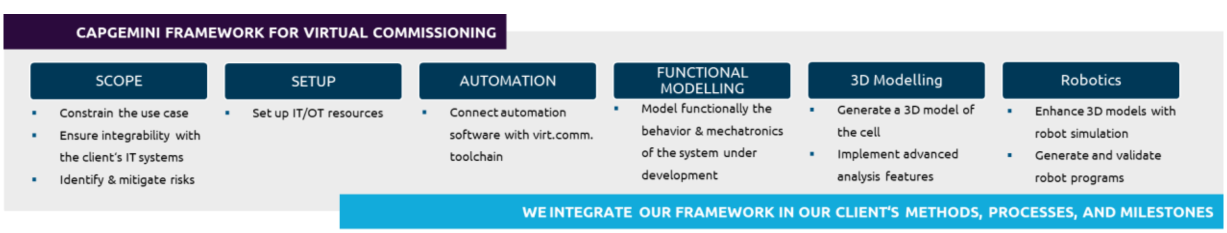


Figure 3 - Capgemini Virtual Commissioning Framework

Developing solutions using this framework enables customers to tackle several business cases

Figure 4 - Virtual Commissioning Business Cases

Normal Course of Events

According to the customer- and project-specific and technical requirements, a software-in-the-loop (SIL) or hardware-in-the-loop (HIL) solution can be developed. The steps to develop these are as follows:

1. **Select a system to purchase or refurbish.** The customer identified an existing need originated from current production sites or from a new program (e.g., new product, platform). The business, process, and technical requirements were defined, and several production concepts will be assessed, evaluated, filtered, and detailed following the generic project lifecycle shown in Figure1.

   From this point forward, the customer must work with the industrial system supplier/Integrator and the virtual commissioning supplier to begin detailing the project scope and to work toward generating the detailed requirements and roadmap for the use case.

2. **Define and detail the project scope.** The customer works with the industrial system and solution providers to define and detail the requirements of the new production system.

In this phase, the enterprise architecture is used as a starting point. Typically, the virtual commissioning technologies are chosen based on the following main questions:

- What is the digital continuity/digital twin strategy of the customer?
- What are the industrial use cases' technical capabilities and feature requirements?
- Does the solution need to be standalone or not?

Information technology (IT) requirements for the chosen technologies and software packages, and the licenses are extracted and documented. This activity is crucial to ensure feasibility and integrability of the technologies and to enable the development and use of the solutions within the targeted environment (e.g., customer IT ecosystem, developer IT ecosystem). The outputs of this activity are used to launch the relevant IT processes in-time to assure IT and firewall exceptions required can be granted.

The system's automation architecture is assessed to understand its overall functionality and to determine an initial estimation of the developing effort to be carried out. A first overview of the solution architecture is drafted, together with an initial overview of the interfaces between the industrial system PLC program and a virtual commissioning solution.

A development roadmap is generated and aligned with the overall industrialization project plan.

3. **Set up IT/OT resources.** Based on the use case requirements, all technologies, IT applications, and resources needed are set up. Technologies and applications are configured and customized based on the project needs and to be able to reuse existing assets developed, such as libraries, drivers, and adapters.

   If the solution to be developed requires hardware (i.e., is a Hardware-in-the-Loop solution), the test bench needs to be designed and assembled. Such test benches are commonly composed of PLC central processing units (CPUs), HMI, switches, and a means of integration between physical and virtual worlds (e.g., a SIMIT virtual controller unit or headers with Input/Output (I/O) cards). An example of such test benches is shown in Figure 5.

   In some cases, consoles and panels such as the ones used by production personnel need to be integrated. This is an activity that is also completed during this phase.

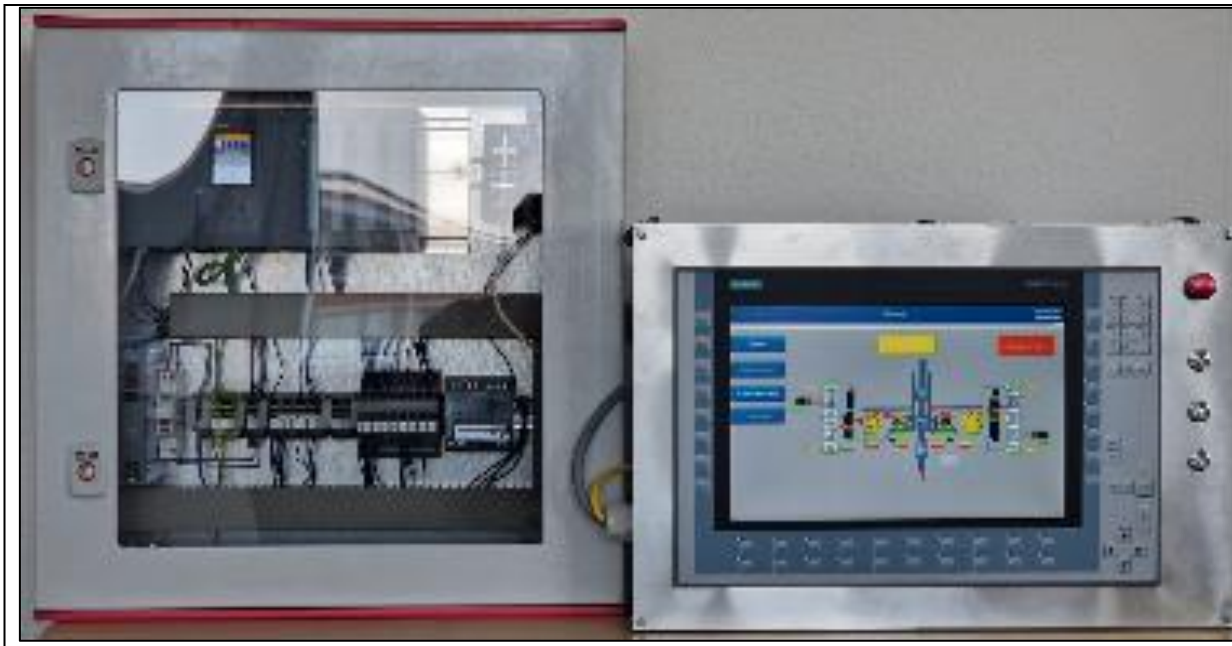


Figure 5 - Virtual Commissioning Business Cases

4. **Automation.** The PLC, automation, or control software is integrated with the virtual commissioning toolchain to enable incremental development, validation, and integration of software.

    - In the case of Hardware-in-the-Loop, a configuration of the hardware modules and components is done according to the system design specification (e.g., automation architecture, network configuration, I/O definition). If development and deployment of Software Blocks (e.g., PLC Function Blocks or Functions) are needed, these are developed, validated, and integrated during this step.

    - In the case of Software-in-the-Loop, connection means (e.g., drivers, connectors, or couplings) are configured based on the system design specification. Once this is done, the virtual commissioning toolchain is integrated with the PLC, automation, or control software and is ready to be used for development and validation.

5. **Functional modeling:** At this step, the virtual commissioning solution development is enabled. The production system that is being designed is used. It is decomposed by following a systems engineering approach to leverage similarities and enforce reuse.

    For example, consider an overhead crane. This has two linear axes, one for translation of the crane through the warehouse and another one for translation of the hook. The crane has a third axis, which is a rotational axis, and is used to lower and raise the crane's hook.

Two sensors (e.g., limit switches) are implemented for each axis for safety. To leverage reusability, two axes are modeled—a linear one and a rotational one. In both cases, the sensor models created are reutilized.

The same approach is followed for all subcomponents and subassemblies of the production mean under development. The interfaces to these models are connected based on the electrical inputs and outputs defined in the engineering documentation (e.g., electrical engineering).

6. **3D modeling.** A 3D manufacturing cell is prepared utilizing the digital mock-up (DMU) and the computer-aided design (CAD) models of the production resources. Kinematics will be implemented to each resource, based on the design constraints and requirements.

   Afterward, the resources is instantiated within the 3D production cell, station, or line. The virtual commissioning capabilities of the solution are implemented, including preparation of inputs/outputs of the 3D cell for each resource, generation of tasks and processes to enable material flow and operations according to the cell requirements. Integration between functional models and 3D models is carried out to enable end-to-end (E2E) integration of all tools.

   In robotics use cases, robotics feasibility studies are carried out within the 3D manufacturing cell. Workspace assessment, safety assessment, reachability, and collision studies are executed first. Afterward, the process-specific technologies are implemented to design the robotic processes. Once these are implemented, the same environment can be used to generate the robot programs utilizing the Off-Line Programming modules from the software packages to program and validate robot tasks through simulation.

   After feasibility is assured at the process and production level, code can be generated using the code generation and postprocessors from the computer-aided manufacturing (CAM) technologies, and that code can be deployed into the virtual robot controller for execution of a virtual commissioning scenario, or into the robot controller to deploy it on-site.

7. **Validate the solution and commission virtually via the production system.** The virtual commissioning solution is used to incrementally develop, verify, and validate the software modules. After validation in the virtual environment, the software can be integrated into the physical production system.

   Additionally, the software-in-the-loop or hardware-in-the-loop solution can be used to train maintenance personnel how to service the machine and production personnel how to operate the machine efficiently without generating any impact to production downtime.

Exemplary Solution Architecture Examples

Solution architecture can vary depending on the platform/applications on which the solution is based. Below are typical applications based on different technologies.

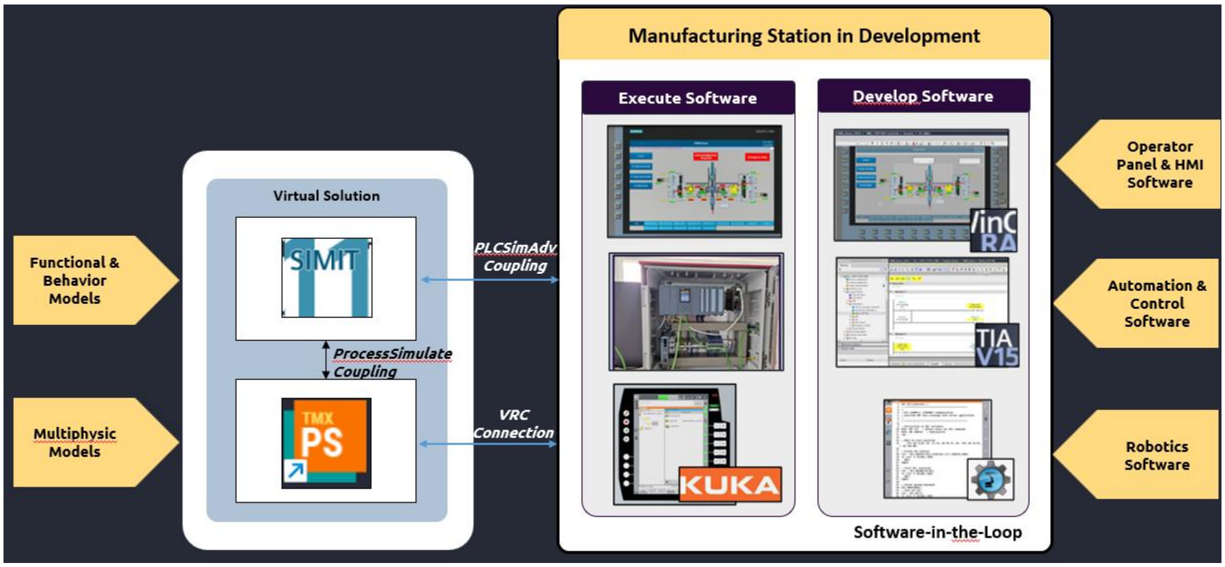


Figure 6 - Siemens-Based Software-in-the-Loop Solution

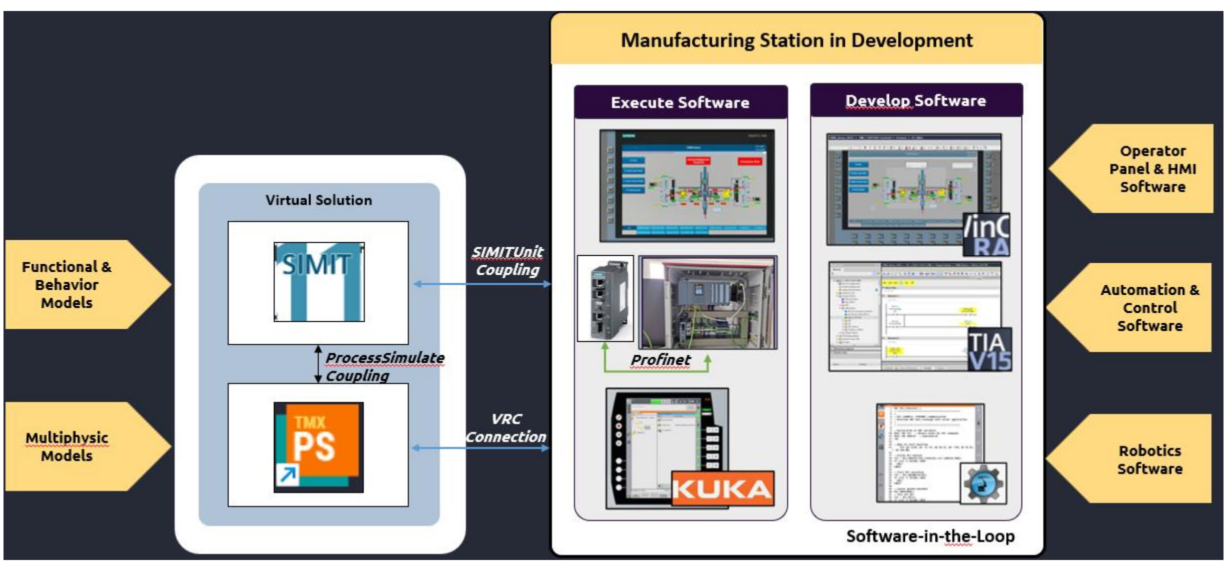


Figure 7 - Siemens-Based Hardware-in-the-Loop Solution

↑ View Digital Twin List ↑ View Digital Thread List

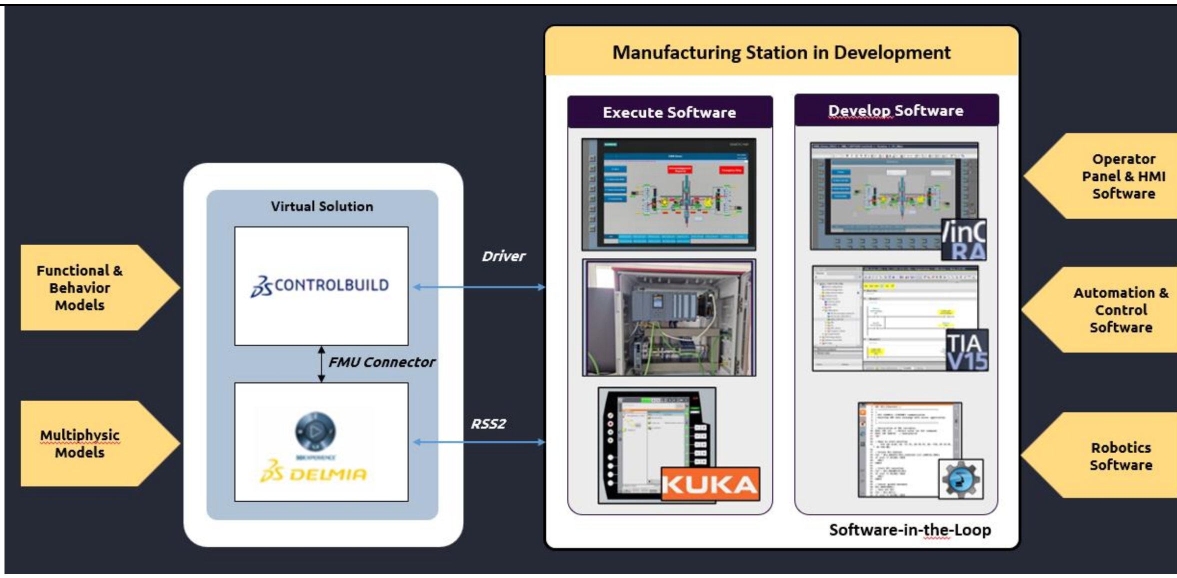


Figure 8 - Dassault (3D Experience)-Based Software-in-the-Loop Solution

Virtual Commissioning Demonstrator

Software-in-the-loop solutions are especially attractive in early phases of the project to quickly validate the software-under-development without needing to duplicate the machine setup in a laboratory. Software modules can be tested, improved, and fully validated before they are integrated and deployed in the program.

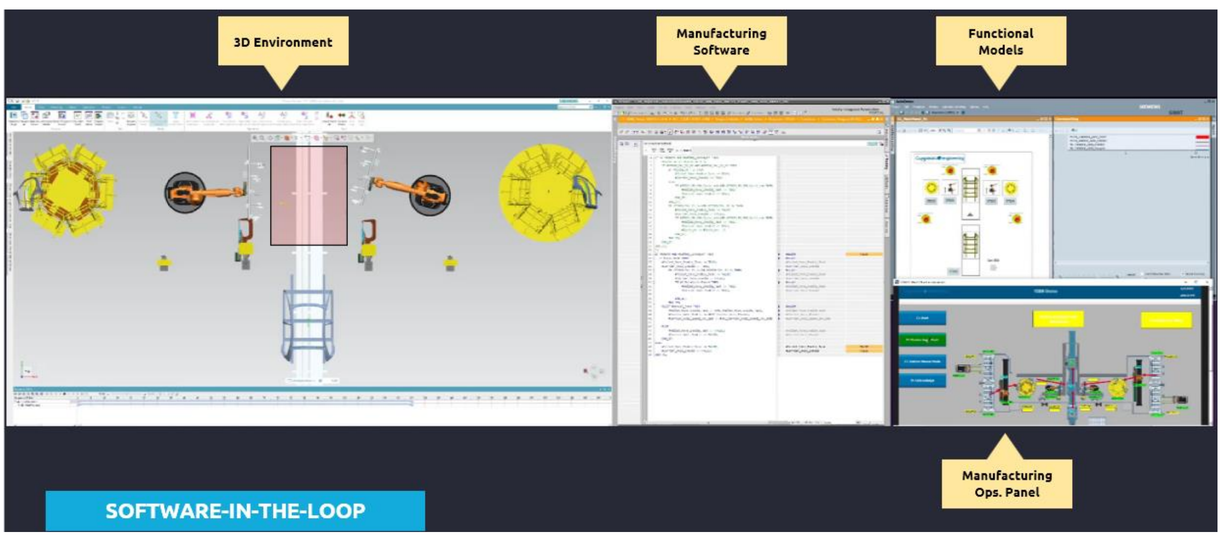


Figure 9 - Siemens-Based Software-in-the-Loop Demonstrator for Body-in-White Assembly Process

As the maturity of the project evolves, hardware components can be integrated to have a hardware-in-the-loop solution. The software (in development or final version) can be executed and validated here. Since the hardware and program of the machine are available, the system can also be used for additional use cases, such as operations and maintenance training.

Figure 10 - Siemens-Based Hardware-in-the-Loop Demonstrator for Body-in-White Assembly Process

UCDtw032: Modeling of Complex Multi-Fidelity, Multi-Domain System-of-Systems (SoS) Mission Scenarios

USE CASE NUMBER: UCDtw032	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: Ansys	**Associated Use Cases:** UCDtw021, UCDtw018
Use Case Title: *Modeling of Complex Multi-Fidelity, Multi-Domain System-of-Systems (SoS) Mission Scenarios*	
Description:	Showcases how the system of systems (SoS) mission modelling capabilities enable seamless modelling, analysis, and insights into the joint operation of digital twins working toward a common objective; a highlight is the synthetic mission environment's ability to simulate multi-fidelity dynamics across multi-domain systems, integrating payloads and subsystems into complex mission scenarios A key advantage of this approach is versatility throughout the entire product development lifecycle—from conceptual design to test and evaluation (T&E) and operations; the integrated framework empowers designers, operational analysts, and mission architects to begin with simplified models and progressively incorporate higher-fidelity simulation outputs Consequently, it is possible to evaluate individual component performance within a broader mission context; moreover, as verification and validation (V&V) advance, flight data and software-in-the-loop /hardware-in-the-loop (SIL/HIL) systems can be integrated with the mission environment, fostering continuously refined, adaptable models that accelerate time to market, pinpoint critical design challenges early, and reduce costs
Goal:	Provide an overview of system-of-systems modelling and simulation capabilities, and how they can be applied at different stages of the lifecycle Address points outlined in UCDtw021 – how multiple digital twins are integrated to create an accurate representation of the entire SoS Address points outlined in UCDtw018 – highlight how type-specific aircraft performance models can be used to determine fuel flows for given flight conditions and parameters
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒

↑ **View Digital Twin List** ↑ **View Digital Thread List**

UCDtw033: Material Modeling Twins As-Built Part / Component Twins for Quality

USE CASE NUMBER: UCDtw033	**USE CASE TYPE: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: Ansys	**Associated Use Cases:**
USE CASE TITLE: *Material Modeling Twins As-Built Part / Component Twins for Quality*	
Description:	Models/simulations of the material structure (e.g., grain structure or precipitates) that include sizes and distributions Calibration of Simulation Material Models using experimental/virtual material behavior data Part/component level models/simulations that include nonconformances and deviations from original engineering releases
Goal:	Reported example of a potential 50 percent reduction in material development time, up to 8 times reduction in testing, and improvement in component capability by integrating material modelling/simulation with design optimization efforts Increase First Time Yield (FTY) during production Reduction in material certification time by up to 25 percent (3-4 years) Support of functional-based dispositioning of components/parts from As-Built reality for quality decisions in Material Review Board (MRB) efforts
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒
Impacted Population:	Less than 10 ☒ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	Materials and Process Engineers (Digital Twin Specialists)
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☒ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒

↑ **View Digital Twin List** ↑ **View Digital Thread List**

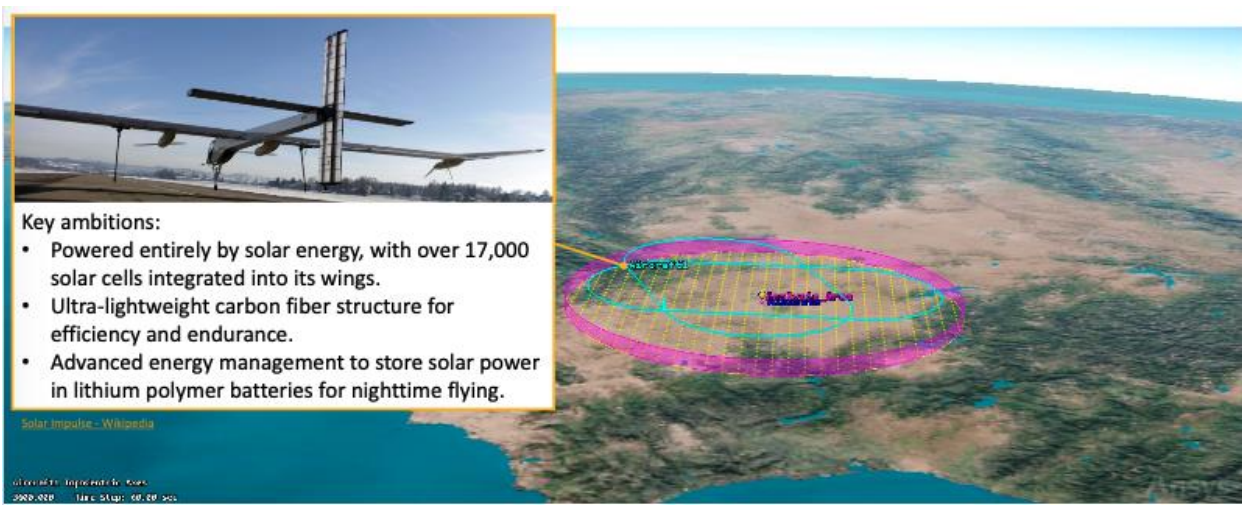
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	Manufacturing Engineers, Systems Engineer, Design Engineer

UCDtw034: Understanding the Performance of a Solar Aircraft Using Digital Twin

USE CASE NUMBER: UCDtw034	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: Ansys	**Associated Use Cases:** UCDtw001, UCDtw002, UCDtw003, UCDtw010, UCDtw011, UCDtw014, UCDtw018
Use Case Title: *Understanding the Performance of a Solar Aircraft Using Digital Twin*	
Description:	This demonstration illustrates how digital twins at the component and subsystem levels can be seamlessly integrated into a comprehensive system-of-systems (SoS) model
Goal:	Showcase the potential of digital twins in A&D by illustrating how digital twins can enhance efficiency, optimize performance, and extend the lifecycle of assets Provide stakeholders with a clear understanding of the practical applications and benefits of digital twin technology in various stages of asset management
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	Digital Twin Architect, Systems Engineer, Simulation Engineer, Computational Modeling Engineer, Internet of Things (IoT) Engineer
Preconditions:	Availability of data and capability to build models
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒

↑ View Digital Twin List ↑ View Digital Thread List

Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	Designers, Maintenance Engineers, Fleet Managers, Systems Engineers
Preconditions:	Suitable information technology (IT) infrastructure
Notes:	



Ansys Developing a Solar Powered Aircraft

UCDtw035: Echo Digital Twin Application Development Framework – Vancouver International and Pearson Airports

USE CASE NUMBER: UCDtw035	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: Capgemini	**Associated Use Cases:** UCDtw016
Use Case Title: *Echo Digital Twin Application Development Framework – Vancouver International and Pearson Airports*	
Description:	The Vancouver International Airport (YVR) Digital Twin Project and the resulting Echo Digital Twin Application Framework (Pearson Project) demonstrate vectors for digital twin technologies in aerospace management, retail, security, emergency response and egress management, and asset management

↑ View Digital Twin List ↑ View Digital Thread List

Goal:	Illustrate the real-time data exchange capabilities and the future prediction capabilities of the Vancouver International Airport (YVR) Digital Twin Project and the resulting Echo Digital Twin Application Framework (Pearson Project), demonstrating how these digital twin applications are utilized in sectors such as aerospace management, retail, security, emergency response and egress management, and asset management
Data:	The design and engineering teams can work with most kinds of data
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☒ Monthly ☒ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	Systems Architecture, Software Architecture, Software Engineering, User Experience (UX) and User Interface (UI) Design
Preconditions:	• Data for use in digital twin exists in a backend system that is accessible from the digital twin application or from provided data files • Computer-Aided Design (CAD) models are provided for buildings, devices, and/or any other item deemed necessary in the digital twin use case
Special Requirements:	• Design team meets with customers for an in-depth analysis of customer requirements of how the digital twin will be used • Software Architect works with client to ensure data availability is met or works with the client to create new architecture to make the data available
Postconditions:	Application development can be performed for any platform, including Windows, Mac, iOS, Android, Augmented Reality (AR), Virtual Reality (VR), and Web

Notes

Echo Digital Twin Application Development Framework – Vancouver International and Pearson Airports

↑ View Digital Twin List ↑ View Digital Thread List

Step	Action	Result
1.	Provide context for a digital twin application in an aerospace context with YVR and Pearson demonstrations (Figures 1 and 2 below)	Context is established and use cases have been demonstrated
2.	Review high-level software architecture for the Pearson digital twin application, and generalized Echo digital twin applications (Figure 3 below)	High-level architecture is modeled and understood
3.	Model backend architecture and synthetic data for the Pearson digital twin application (Figure 4 below)	Pearson digital twin backend technical understanding is established, and synthetic data usage is modeled
4.	Model frontend architecture and the Unity tech stack for the Pearson digital twin application, and model how the Unity engine is utilized to create digital twin applications (Figure 5 below)	Pearson frontend technical understanding is established; the Unity tech stack is discussed and understood in the context of a digital twin application
5.	Model the Accelerator Packages (Echo packages) and their application in the Pearson and Burnaby digital twins (Figure 6 below)	Accelerator packages are defined and illustrated; Burnaby digital twin is demonstrated and understood

↑ **View Digital Twin List** ↑ **View Digital Thread List**

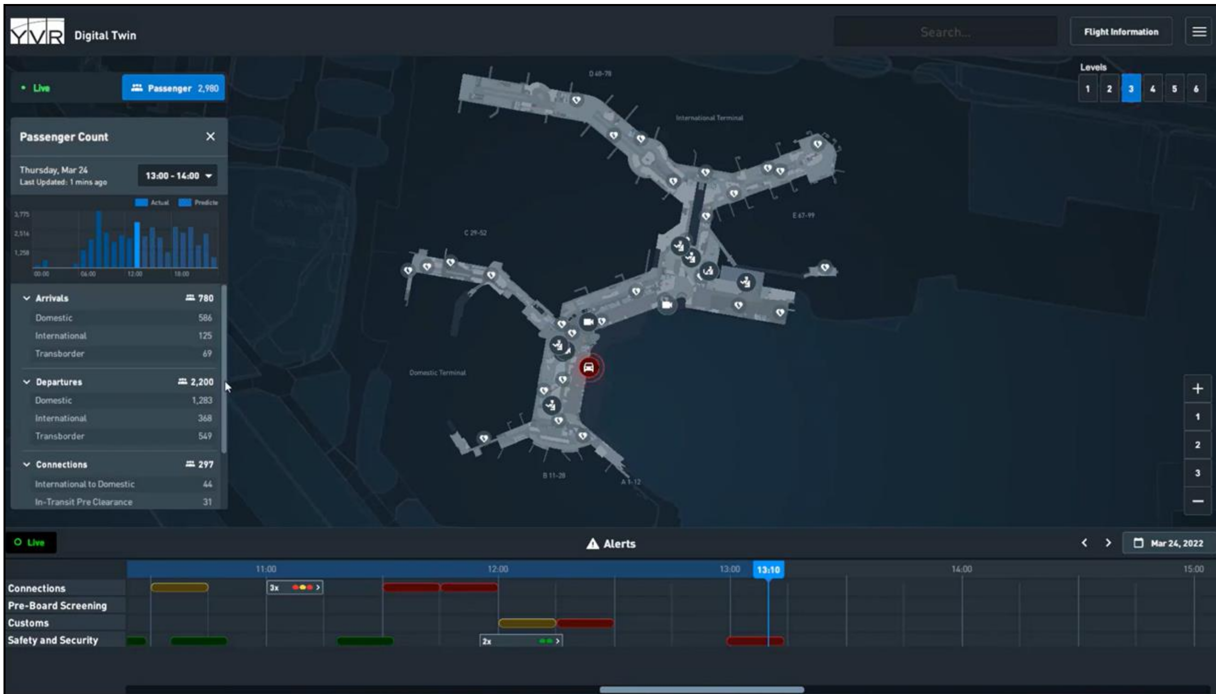


Figure 1 – YVR Digital Twin

Link: [YVR's Digital Twin briefing]()

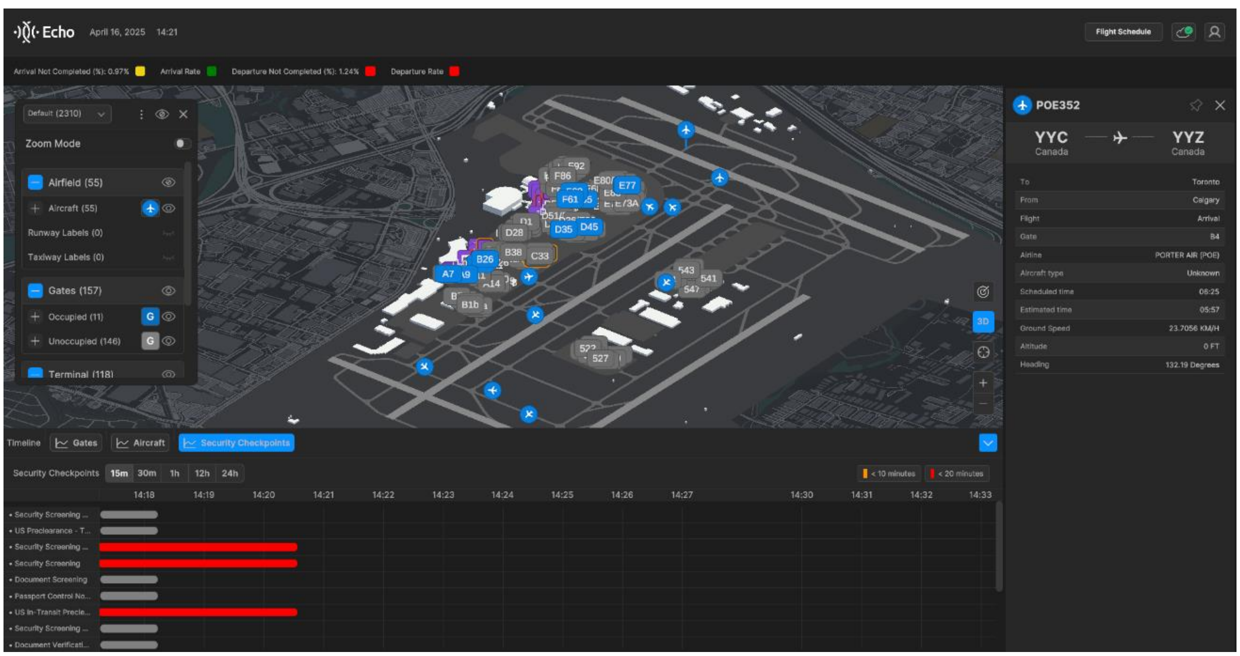


Figure 2 – Pearson Digital Twin

↑ [View Digital Twin List]()   ↑ [View Digital Thread List]()

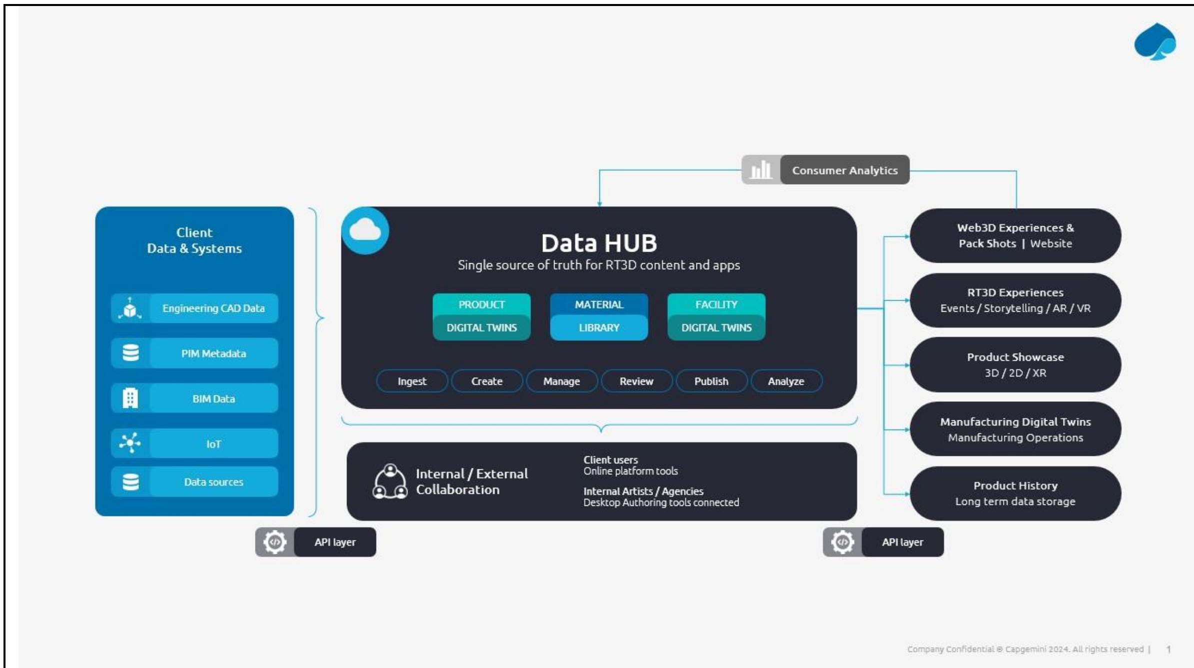


Figure 3 – Echo Digital Twin High-Level Architecture

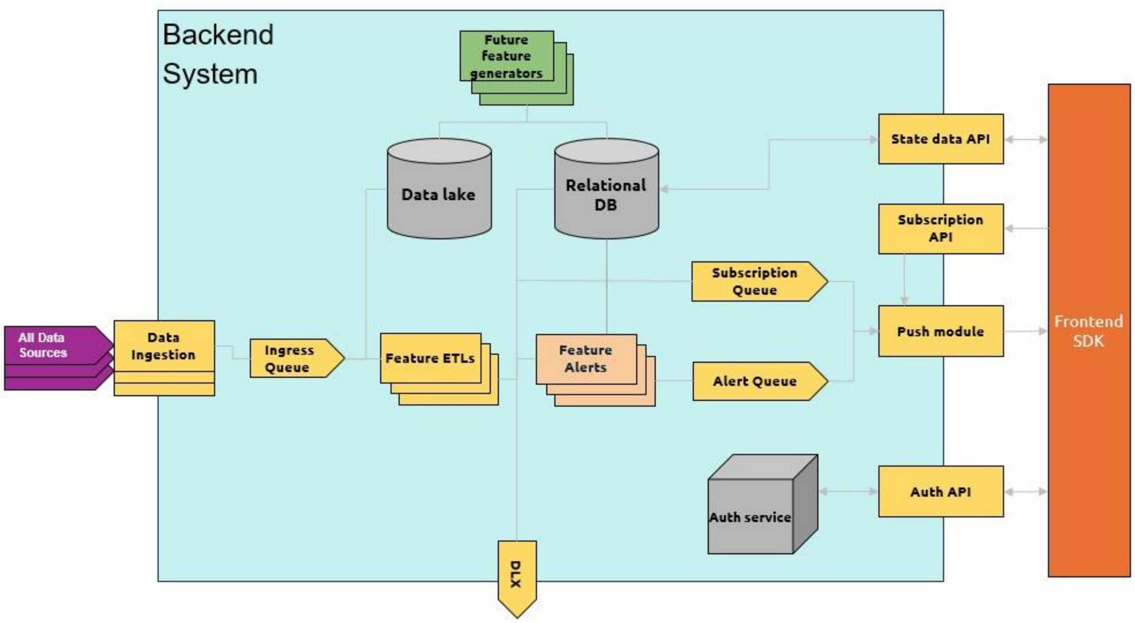


Figure 4 – Pearson Digital Twin Backend Architecture

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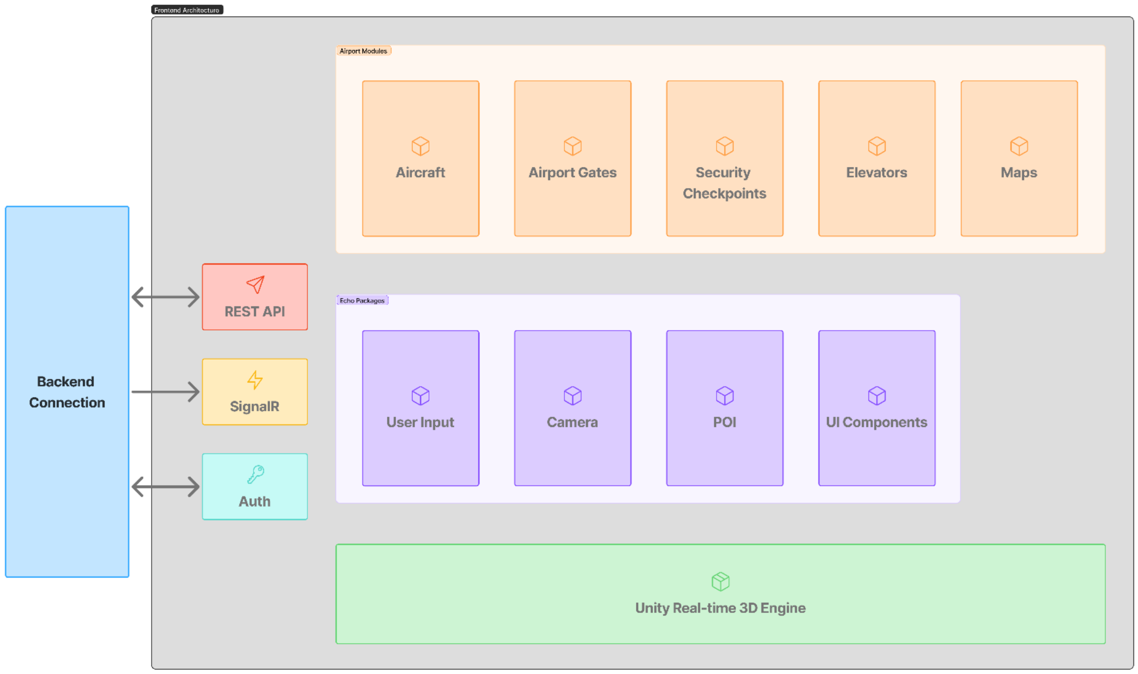

Figure 5 – Pearson Digital Twin Frontend Architecture

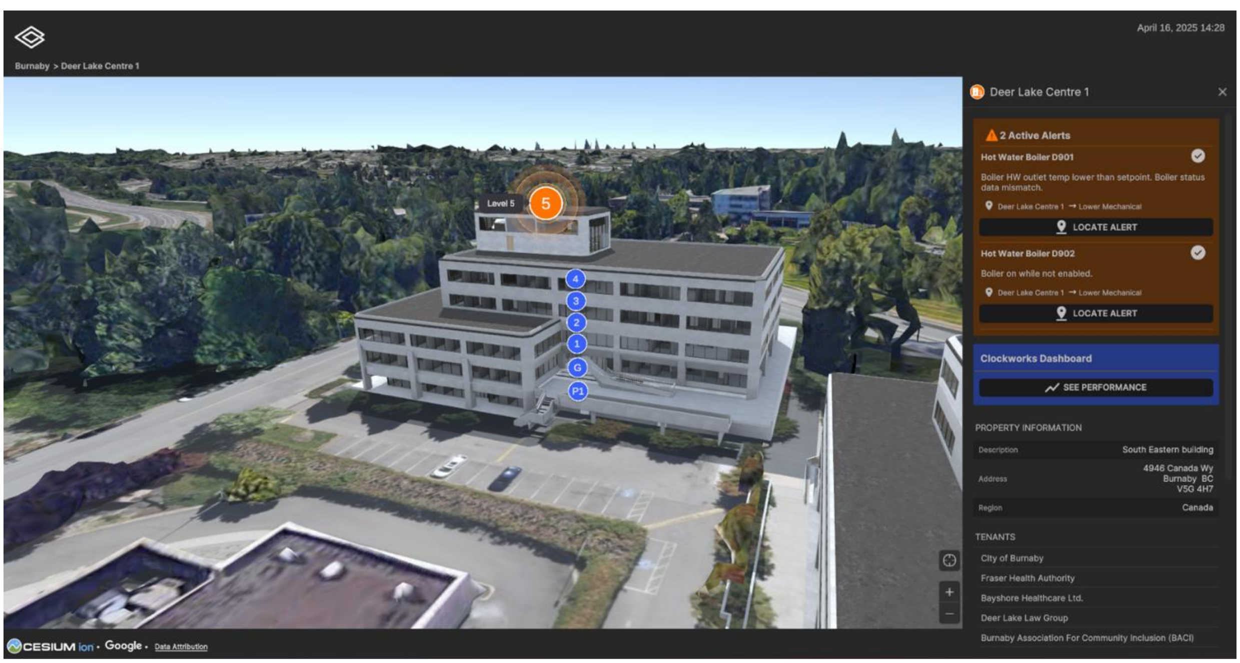

Figure 6 – Burnaby Digital Twin

↑ [View Digital Twin List]   ↑ [View Digital Thread List]

Additional Use Cases

The following digital twin use cases, presented in numerical order, were prepared (in varying degrees of detail) but not demonstrated.

UCDtw001: Digital Twin Calibration

<table>
<tr><td colspan="2">USE CASE NUMBER: UCDtw001</td><td>Use Case Type: Digital Thread ☐ Digital Twin ☒</td></tr>
<tr><td colspan="2">Use Case Owner: AIAA-DEIC</td><td>Associated Use Cases:</td></tr>
<tr><td colspan="3">Use Case Title: Digital Twin Calibration</td></tr>
<tr><td>Description:</td><td colspan="2">Validation/Calibration of digital twins based on real-world product operational data/conditions (e.g., coupon tests, wind tunnel tests, ground tests, flight tests, operational tests); digital twin calibration examples follow:
1) Ops Analysis - Models to develop mission planning survivability, and tactics
2) Structural - Finite Element Model (FEM) for Loads and Life management
3) Variation - Reflecting tolerances and variation in parts and tooling to identify statistical fit issues ahead of first article
4) Vehicle Systems - Modeling and simulation of product systems/subsystems
5) Flight Controls - Modeling and simulation of vehicle flight controls
6) Mission Systems - Modeling and simulation of mission systems/software
7) Signature - Model that captures initial design and repairs that impact Radar Cross Section (RCS)
8) Sustainment - Modeling and simulation of product sustainment</td></tr>
</table>

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Goal:	Improve product design and first-time quality through more accurate and higher fidelity design models and analytical methods Enable accelerated decision-making based on a validated authoritative source of truth (ASoT) 1) Ensures that the product design is optimized to achieve mission performance objectives 2) Validates structural loads and product structural life projections 3) Is in use with metrology measurements to identify and prevent part variation that can cause impacts to early article manufacturing 4) Validates the design and performance of product systems to reduce lab/flight testing 5) Enables control law development to optimize flight dynamics and support pilot training 6) Validates the design and performance of mission systems to reduce lab/flight testing 7) Validates product survivability and operational mission performance 8) Validates product maintenance/sustainment approach, basing requirements and equipment
Data:	

UCDtw002: Performance Monitoring, Validation, and Optimization

USE CASE NUMBER: UCDtw002	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**
Use Case Title: *Performance Monitoring, Validation, and Optimization*	
Description:	Virtually validate product performance while also showing how products are currently acting in the physical world to optimize performance Embed Serial Number adapted closed-loop controls for operational and environmental factors to operate closer to performance boundaries
Goal:	Lower system cost for target performance (avoid design margin from over-engineering and/or reduce requirements for materials/physical performance via in- product adaptive controls); for example, active load reduction on wind turbines through angle of attack adjustment
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐

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Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐

UCDtw003: Design Optimization and Upgrade Analysis

USE CASE NUMBER: UCDtw003	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**
Use Case Title: *Design Optimization and Upgrade Analysis*	
Description:	A 10-75% reduction in cycle time improves the quality of the final manufactured product and enables faster iterations in response to customer feedback; this enables product version evaluation to determine which features provide the optimal solution Data analytics can facilitate timely analysis of volumes of data generated to provide insights into potential new products and revenue streams
Goal:	Analyze product performance under various conditions and make adjustments in the virtual world to ensure that the next physical product will perform exactly as planned in the field Reduce iterations through early discovery of downstream stakeholder conflicts (e.g., fewer Maintenance Review Boards)
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐

UCDtw004: Market Gap Analysis and Capabilities

USE CASE NUMBER: UCDtw004	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**
Use Case Title: *Market Gap Analysis and Capabilities*	
Description:	• Analysis of alternatives for capability/need assessment • Reduction of time to develop and certify through high fidelity analysis from a digital twin
Goal:	Analyze alternatives and reduce development and certification time

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Data:				
Digital Twin Development				
Use Case Lifecycle Stage:	A-Concept ☐ E-Support ☐	B-Development ☒ F-Retirement ☐	C-Production ☐	D-Utilization ☐
Digital Twin Utilization				
Use Case Lifecycle Stage:	A-Concept ☐ E-Support ☐	B-Development ☒ F-Retirement ☐	C-Production ☐	D-Utilization ☐

UCDtw005: As-Built Configuration

USE CASE NUMBER: UCDtw005	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**
Use Case Title: *As-Built Configuration*	
Description:	Details of the aircraft As-Built configuration that are not associated with the engineering configuration such as serial numbers, cage codes, sustainment data loads, measurements during build, nonconformance documentation, supplier disclosures, and added inspections As-Built configuration contains nonconformance information, repairs, post-delivery article inspection requirements, supplier disclosure notifications, and factory test data required for aircraft or sustainment data loads
Goal:	Value is to provide the customer a complete record of the As-Built configuration and highlight where the configuration may differ from the engineering configuration to support sustainment maintenance and modifications (this assumes mainly automated data collection and accumulation)
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐

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UCDtw006: Performance Validation and Optimization

USE CASE NUMBER: UCDtw006	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒	
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**	
Use Case Title: *Performance Validation and Optimization*		
Description:	Model of aircraft production performance, including task span times, hours per unit, and sequence of operations	
Goal:	Twin provides descriptive and predictive insight into factory performance (cost, quality, schedule) to support learning curve estimates, staffing and tooling requirements, and trends to identify opportunities for continuous improvement	
Data:		
Digital Twin Development		
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐	
Digital Twin Utilization		
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐	

UCDtw007: Factory Simulation

USE CASE NUMBER: UCDtw007	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒	
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**	
Use Case Title: *Factory Simulation*		
Description:	Discrete event and digital physical modelling to simulate physical factory layout, materials flow, and tooling, and to identify bottlenecks and the results of disruptions to the factory operations, such as quality or parts problems	
Goal:	Factory physical and statistical models simulate factory operations to validate product fit and flow along with identifying bottlenecks and helping to identify requirements (staffing, tooling, and support staff) as factories expand to full rate of production Twin value is to accurately predict requirements for the factory and enable stable production even as rates rise and disruptions impact the factory Dynamic scheduling to identify critical path impacts and mitigation strategies	
Data:		

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Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐

UCDtw008: Material Modeling Twins As-Built Part / Component Twins for Quality

USE CASE NUMBER: UCDtw008	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**
Use Case Title: *Material Modeling Twins As-Built Part / Component Twins for Quality*	
Description:	Models/simulations of the material structure (e.g., grain structure or precipitates) that include sizes and distributions Part/component level models/simulations that include nonconformances and deviations from original engineering releases
Goal:	Provide virtual representation of a physical entity, its behaviors, and the associated processes to enable models/simulations of the material structure and part/component level models/simulations. Reported example of a potential 50 percent reduction in material development time, up to 8 times reduction in testing, and improvement in component capability by integrating material modeling/simulation with design optimization efforts Reduction in material certification time by up to 25 percent (3-4 years) Support of functional-based dispositioning of components/parts from As-Built reality for quality decisions in Material Review Board (MRB) efforts
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐

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UCDtw009: Performance Monitoring

USE CASE NUMBER: UCDtw009	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒	
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**	
Use Case Title*: Performance Monitoring*		
Description:	Cross-fleet, asset-to-asset, operator-to-operator performance normalization to environmental and multi-granular operational baselines	
Goal:	Provide virtual representation of a set of aircrafts, their behaviors, and associated processes to: Improve forecasting and just-in-time inventory planning, predict and control impact of performance drift, product variation, and use context Reduce time to identify and correct sub-performing units (e.g., turbines across a wind farm) and optimize for Key Performance Indicators (KPIs), for example energy production/AEP) Serial number (SN) and part number (PN) model calibration and convergence through continual learning, leading to robust, reliable asset performance forecasting relative to contextual degradation	
Data:		
Digital Twin Development		
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐	

UCDtw010: Fleet Enterprise Twin

USE CASE NUMBER: UCDtw010	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒	
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**	
Use Case Title: *Fleet Enterprise Twin*		
Description:	Product level (SN-specific) models/simulations which include As-Operated data (e.g., Equipment Health Monitoring and Environmental context data) to inform maintenance decisions & feedback to operator to improve performance	

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Goal:	Provide virtual representation of an aircraft, its behaviors, and the associated processes to: Use modeling/simulation of the asset to assess current operating context Provide recommendations to minimize fuel burn and signal when asset needs maintenance Enable learning from asset's operations and other engines in the fleet Apply the GE Trip Optimizer™ for 10% fuel reduction
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐

UCDtw011: Health Status Validation and Optimization

USE CASE NUMBER: UCDtw011	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**
Use Case Title: *Health Status Validation and Optimization*	
Description:	Failure prediction and predictive maintenance: • Incipient failure detection to adapt operation to life- extending mode so failure does not precede service • Predictive part needs for long-lead manufacture or distribution logistics
Goal:	Provide virtual representation of an aircraft, its behaviors, and the associated processes to enable improved control and performance toward condition-based operation. Challenges: • Sensor diagnostics (higher accuracy/lower lead time) getting adequate lead time to act from time of detection • Predictive algorithms' ability (lower accuracy/longer lead times) to catch sensor-elusive failure modes (e.g., cracks)
Data:	

Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐

UCDtw012: Failure Analysis

USE CASE NUMBER: UCDtw012	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**
Use Case Title: *Failure Analysis*	
Description:	Root Cause Analysis (RCA) based on part/component-specific full-genealogy (i.e., As-Designed, As-Manufactured, As-Operated, As-Serviced) and detailed operational use data New failure modes (unknown unknowns) are identified in operational data via unsupervised manifold learning for anomaly detection
Goal:	Provide virtual representation of a physical entity, its behaviors, and the associated processes to enable: Reduce downtime diagnosing ambiguous cause, learnable scope of impact across fleet to adjust preventative maintenance schedules for peer assets, and recalibrations for condition-based maintenance. Improve re-designs building on learned field performance versus As-Designed for baseline design
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐

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UCDtw013: Condition-Based Maintenance

USE CASE NUMBER: UCDtw013	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**
Use Case Title: *Condition-Based Maintenance*	
Description:	Feedback from sensors enables condition-based maintenance, fatigue life analysis, and severe event tracking Risk-based work scoping is based on predicted life versus service duration and interval to next service (e.g., tailored maintenance actions by individualized predicted part life and operational projection to next maintenance event)
Goal:	Provide virtual representation of a physical entity, its behaviors, and the associated processes to enable: Improved product reliability and availability and lower maintenance costs. For example, GE Digital saw a 6% increase in product reliability, a 40% reduction in maintenance costs, and an $11M in cost avoidance by using digital twins to detect and prevent three failures Improved service-ready inventory of replacement parts to provide a “full kit” at maintenance Reduction of unplanned downtime, extraneous waste, and cost from premature part replacement; greater duty cycle for operation; and improved at maintenance Reduction of unplanned downtime, extraneous waste, and cost from premature part replacement, resulting in a greater duty cycle for operation and improved just-in-time maintenance reliability
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐

UCDtw014: End-of-Life Decision Aid

USE CASE NUMBER: UCDtw014	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AIAA-DEIC	**Associated Use Cases:**
Use Case Title: *End-of-Life Decision Aid*	

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Description:	Part/component-level model evaluating As-Used versus As-Designed versus As-Repair(able)
Goal:	Provide virtual representation of a physical entity, its behaviors, and the associated processes to: Advise the decision to reuse, recondition, recycle, or scrap, based on the historical operational environment Reduce scrap, service costs, remanufacturing costs, and downtime Challenge: Predictive accuracy beyond operational and environmental factors, due to multi-granular twin variability (i.e., part-to-part versus engine-to-engine)
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐

UCDtw015: As-Operated Digital Twin

USE CASE NUMBER: UCDtw015	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *As-Operated Digital Twin*	
Description:	The As-Operated product digital twin is a digital representation of the aircraft in operation with the up-to-date configuration that simplifies access to the related data and services

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Goal:	Global business purpose served by the product digital twin is as follows. The As-Operated digital twin will provide: • Better efficiency in engineering support (fleet efficiency management) • A simplified way to monitor fleet assets (e.g., residual value assessment, maintenance plan, support for end-of-lease) • Easy access to technical data due to a configured digital mockup • Continuous product monitoring for design improvement (i.e., to generate a feedback loop) • Operations improvement due to training with accurate models (for Virtual Reality/Augmented Reality - VR/AR) • An environment to train artificial intelligence (AI) models for computer vision (e.g., quality inspection) • An interrogable digital avatar of the aircraft in the system of systems (SoS) for better integration into the airport's environment
Data:	• Aircraft configuration • Digital mockup of an individual aircraft (identified by its manufacturing serial number) • Maintenance execution data • Operations data
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☒ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	Co-created by Engineers, Manufacturing Engineers, Support Engineers
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production* ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒ * End of production
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒
Roles:	Aircraft Original Equipment Manufacturer (OEM); Airlines, Lessors; Maintenance Repair and Operations Stakeholders; Airports and Ground Handling Companies; Suppliers (company to provide parts); Environmental Stakeholders (to contribute to climate change monitoring, for example)

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UCDtw016: Digital Engine

USE CASE NUMBER: UCDtw016	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AD PAG	**Associated Use Cases:**
***Use Case Title**: Digital Engine*	
Description:	This solution is an aggregate of five different software objects. It is composed of two primary parts: • Generic avatar. This is the theoretical representation of the engine, made from the As-Designed BOM characteristics and 3D models. It is built by the design offices on the development side • Digital twin. This is the physical representation of the engine, made from the As-Built BOM; it also contains eventual non-compliances and their sanctions-associated measurements One Generic Avatar can instantiate multiple digital twins
Goal:	The main goals of the digital engine are to: • Allow users to freely and transparently navigate through all five software objects without having to recreate the links between these objects • Monitor consistency and quality of data throughout all the software objects • Manage the concessions with complex criteria • Work on data quality and coherency of upstream software objects
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	Design offices from development to aftersales; Program team
Preconditions:	Extracts of direct links to upstream software objects must be available to retrieve the data from them. Data of upstream software objects can have variable quality, but it should fit the global data model (i.e., unique identification of an item or an instance of an item)

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Special Requirements:	A 3D visualization tool that does not require a Computer Architecture and Organization (CAO) computer should be available
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	Design offices from development to aftersales; Program team
Special Requirements:	Steady internet connection to show the 3D Digital Mock-Up (DMU)

UCDtw017: Digital Twin Airport Operations

USE CASE NUMBER: UCDtw017	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Digital Twin Airport Operations*	
Description:	Aircraft operators can incur costly delays and inefficiencies due to lack of service availability while on the ground, relating to airport layouts and gate/stand allocation (e.g., ground-power, connectivity – maintenance data offload and software part upload – payload logistics, and refueling)
Goal:	Provide virtual representation of a set of aircrafts, their behaviors, and the associated processes to improve restricted on-ground connectivity to improve ground operations performance and reduce overall airport delays
Data:	• Airport Operations • Airline Operations • Ground Operations
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☐ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☒ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐

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Roles:	Airport Operations, Airline Operations, Ground Operations
Preconditions:	None
Special Requirements:	None
Postconditions:	None
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☒ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	Airport Operations, Airline Operations, Ground Operations
Preconditions:	None
Special Requirements:	Real-world data is required to enable the digital twin and can be obtained from analysis of the available airport, airline, and ground operations data sources
Postconditions:	None
Notes:	None

UCDtw018: Aircraft Performance

USE CASE NUMBER: UCDtw018	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Aircraft Performance*	

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Description:	Aircraft performance models and estimates of key factors, such as wind, play the most crucial role in designing efficient flight trajectories for key segments of long-haul flights Currently, ground-based flight planning systems utilize aircraft-type-specific performance tables to determine fuel flows for given flight conditions and parameters, such as altitude, mass, and speed; the tables are corrected by a performance factor as the aircraft ages
Goal:	Provide virtual representation of an aircraft, its behaviors, and the associated processes to improve aircraft performance modelling
Data:	• Aircraft Performance (fuel flow, speed, thrust, weight) • Weather (wind, direction)
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☒ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☒ Other ☒ Other: Creation at aircraft design; unique digital twin for each aircraft
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒
Roles:	Designer, Engineer
Preconditions:	• OEM aircraft performance baseline • Airline aircraft operations performance baseline
Special Requirements:	None
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☐ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☒ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	Pilot, Air Traffic Control, Airline Operations Center, NOAA-Weather Forecasting
Preconditions:	Availability of aircraft operational data

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UCDtw019: Digital Twin Extraction and Interoperability of Data Components

USE CASE NUMBER: UCDtw019	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: OMG	**Associated Use Cases:**
Use Case Title: *Digital Twin Extraction and Interoperability of Data Components*	
Description:	Specifies technical aspects related to the extraction, decoupling, trading, and benefits of data components in a digital twin ecosystem
Goal:	Better understanding of the technical aspects of creation and utilization of digital twins
Data:	

UCDtw020: Digital Twin Framework for the Automation and Integration of Manufacturing Systems

USE CASE NUMBER: UCDtw020	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner: OMG	**Associated Use Cases:**
Use Case Title: *Digital Twin Framework for the Automation and Integration of Manufacturing Systems*	
Description:	Utilize a framework to support the creation of digital twins of observable manufacturing elements including personnel, equipment, materials, manufacturing processes, facilities, environment, products, and supporting documents
Goal:	Provide virtual representation of a manufacturing system, its behaviors, and the associated processes to enable optimization of productivity and other operational aspects
Data:	

UCDtw021: System-of-Systems Digital Twins

USE CASE NUMBER: UCDtw021	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒	
Use Case Owner: OMG	**Associated Use Cases:**	
Use Case Title: *System-of-Systems Digital Twins*		
Description:	The joint operations of digital twins of different military assets working together towards a joint common objective; this use case demonstrates the interactions between different systems, establishing the granularity of the data to be utilized by digital twins having different levels of accuracy Challenges: • Integrating multiple digital twins to create an accurate representation of the entire System-of-Systems (SoS) • Requiring a significant amount of data to validate the model and ensure that the model accurately reflects the behavior of the real-world system of system	
Goal:	Provide virtual representation of multiple physical assets, their behaviors, and the associated processes to enable optimization as a system of systems.	
Data:		

UCDtw022: Intelligent Digital Twin

USE CASE NUMBER: UCDtw022	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒	
Use Case Owner: OMG	**Associated Use Cases:**	
Use Case Title: *Intelligent Digital Twin*		
Description:	Following the presumption that a digital twin captures the behavior of is a type of simulation of a physical objects/system, an intelligent digital twin would at a minimum use artificial intelligence (AI) to simulate the physical object system's decisioning capability and human interaction with the physical object	
Goal:	The use of AI may improve the efficiency of digital twins by providing insights that go beyond what real-world sensors provide by augmentation with Industrial Internet of Things (IIoT) data generated by physical objects systems; this will require the use of digital twin AI to simulate the physical objects systems IIoT data From a predictive simulation perspective, AI can independently decide which tests it needs to run based on the data it receives, and it can then predict which actions would achieve the desired outcomes	
Data:		

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Digital Thread Use Cases

The digital thread use cases are sorted by subgroup. In the index table, use cases that were demonstrated are listed first, and additional use cases that were defined during the project but not demonstrated are listed after. Use cases were assigned an identifier during the project, and they are listed in numerical order within their subgroup. Each listing includes a hyperlink to the use case write-up. Following the index table, Demonstrated Use Case write-ups are presented first, and Additional Use Case write-ups are presented after.

Contributor	Digital Thread Title	Description	Lifecycle Stage
		Demonstrated Use Cases	
AD PAG	UCDth006: Concession Management	As-Built versus As-Designed nonconformities that require Design Office approval (SAE equipment) if concession management means the concessions are back to PLM; frequently, a concession from production is reported as a defect to the Customer Service Center and is later determined to be a false positive	B, C, D, E
AD PAG (Infosys Demo)	UCDth022: Production and Support: AI-Enhanced PLM-MES integration for Manufacturing Conformance Management	Native digital data traceability from Product Lifecycle System (PLS) As-Designed to recording in the Manufacturing Engineering System (MES) during production operations to confirm conformity before delivery	B, C, E
Hexagon	UCDth035: Collaborative System Engineering	Connecting design and simulation engineers onto the same 3D system model allowing faster design optimization iterations in real time	A, B
Hexagon	UCDth036: End2End Additive Manufacturing	Connecting component CAD data with 3D printing machine data and metrology (quality control) machines to enable a virtuous data loop allowing to automatically refine machine parameters and component design based on an advanced quality-controlled process	A, B, C
Hexagon	UCDth038: Virtual Assembly	Using 3D geometry data of the real parts being manufactured to virtually predict the compliance of next assembly system; and subsequent corrective actions needed if not compliant	B, C
Hexagon	UCDth039: Digital Thread End-to-End Automated Inspection	Connecting quality reports along the manufacturing process with manufacturing process data to enable process deviation and out of tolerance issues as soon as possible (ASAP) and provide guidance to correct the process	A, B, C

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Contributor	Digital Thread Title	Description	Lifecycle Stage
Capgemini	UCDth044: Solution Architecture Model	Showcase how a solution architecture framework in a modeling tool such as DS CATIA Magic (formerly No Magic Cameo) can enhance collaborative model-based practices across an organization by connecting digital thread use cases to the technical solution	A, B, C
PROSTEP AG	UCDth046: OpenCLM - Cross System / Domain Impact Analysis	Utilizing OpenCLM with connectors to various other systems demonstrates OpenCLM operation, process templates, linking data from external sources, evaluating impact analysis, visualizing impacts through data graph visualization Separate software solutions exist that are data repositories and Authoritative Sources of Truth (ASOT) for domain data; utilizing OpenCLM with connectors to PLM, MBSE, ALM, ERP, or other systems demonstrates OpenCLM operation, process templates, linking data from external sources, evaluating impact analysis, and visualizing impacts though data graph visualization	A, B
PROSTEP AG	UCDth047: OpenCLM - Integrated Enterprise Configuration Lifecycle Management (CLM) and Baselining	Data representing the Authoritative Source of Truth (ASOT) for multiple domain tools is distributed between multiple repositories Configuration management of the system requires alignment of artifacts controlled in each system at product milestones, such as releases, builds, or other snapshots in time OpenCLM is a tool for creating the digital thread though integrated data; this allows for linking data from connected systems, provides semantic relationships between them, and creates immutable baselines of the data in OpenCLM for permanent configuration records	A, B, C, D, E
PROSTEP AG	UCDth048: OpenPDM - Cameo PLM Integration	A variety of integration solutions for DS Cameo include a Cameo client plugin, integration through Open Services for Lifecycle Collaboration (OSLC) for the Cameo Datahub, and Teamwork Cloud Connector integration. Integration of the Authoritative Source of Truth (ASOT) data with the primary model-based systems engineering tool	A, B

Contributor	Digital Thread Title	Description	Lifecycle Stage
eQ Technologic	UCDth049: A Day in the Life of Data Workers with an Automated Digital Thread	eQube®-DaaS (Data as a Service) coupled with the eQube-DTA (Digital Thread Application) provides an integrated data fabric stitching data, applications, and devices through all the phases of a product development lifecycle while honoring data security, maintaining digital thread (DT) configuration management, and providing user search and navigation on a single screen; this solution results in dramatic improvements in productivity, quality, unparalleled insights, and access to data within and between the enterprise systems This use case “walks” through a day in the life of an integrated digital product development environment and demonstrates the automated creation and maintenance of a digital fabric with configuration-controlled DTs across Commercial off-the-shelf (COTS), Government off-the-shelf (GOTS), and internally developed enterprise applications while honoring the data security models within each of these applications eQ-Technologic will show the integration of data between Jira, DOORS NextGeneration, Capella, Minerva, Windchill, SAP, and Solumina The eQube-DaaS platform and eQube-DTA are designed to be future-proof, system agnostic and are built to enable adding, removing, and changing applications through the life of the product, allowing customers to incorporate new technologies as required	A, B, C, D, E, F
Capgemini	UCDth050: Digital Engineering Certification Solution (DECS)	Accelerating the digital aircraft certification process within a comprehensive tool landscape, including a digital ledger	A, B, C, D, E
Cortona3D	UCDth051: Technical Documentation in the Digital Thread	Develop technical documentation based directly on product data for manufacturing and service	C, D, E

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Contributor	Digital Thread Title	Description	Lifecycle Stage
AD PAG and Cortona3D Notes	UCDth052: Cross-Discipline Engineering	Accessibility and traceability of mechanical, electrical, electronics, and embedded software product content to cross-disciplinary engineering teams	A, B
Cortona3D	UCDth053: Long-Term Data Archival and Retrieval	Long-term maintenance of data, including archival and retrieval of digital product and technical data. Archiving is required until the product's End of Life (EOL)	A, B, C, D, E, F
AD PAG and Cortona3D Notes	UCDth054: Interactive Production and Maintenance	Interact with products based on augmented reality using models and technical documentation	E
eQ Technologic	UCDth056: Generation, Configuration Management, and Impact Assessment of the Digital Thread	eQube®-DaaS (Data as a Service) coupled with the eQube-DTA (Digital Thread Application) provides an integrated data fabric stitching data, applications, and devices through all the phases of a product development lifecycle while honoring data security, maintaining digital thread (DT) configuration management, and providing search and navigation in a single screen; this solution results in dramatic improvements in productivity, improved quality, unparalleled insights, and access to data within and between the enterprise systems This use case features eQube-DTA, showing how a thread specification is created to filter the digital fabric for specific individuals/roles, how to use permissions and sharing capabilities, and how this tool makes possible impact assessment and conversations on the thread for an engineering review The eQube-DaaS platform and eQube-DTA are designed to be future-proof, system agnostic, and are built to enable adding, removing, and changing applications through the life of the product, allowing customers to incorporate new technologies as required	A, B, C, D, E, F

↑ View Digital Twin List ↑ View Digital Thread List

Contributor	Digital Thread Title	Description	Lifecycle Stage
Ansys	UCDth057: Design of Axial Compressor for Gas Turbine Engine	This workflow focuses on the design of an axial compressor (continuously pressurizes gases) for a gas turbine engine through its various phases and stages of development from concept to the detailed design of a blade to the overall production of the compressor	A
Ansys	UCDth058: Model-Based Systems Engineering and Associated Topics	Model-Based Systems Engineering (MBSE) and associated topics: UCDth009 Closed-loop requirements linking and traceability through design, simulation, prototype and test UCDth010 Modelling, simulation, and virtual analysis at all stages of the Requirement, Functional, Logical, and Physical (RFLP) UCDth011 Digital thread ecosystem — Original Equipment Manufacturer (OEM) - Manufacturing - Supplier (OEM-MFG-Supplier) — for field change impact analysis; connection between early engineering to field support, suppliers, and partners; bidirectional traceability and enabling suppliers to engage key data via digital thread UCDth015 Traceability of design rationale from early conceptual architecture through in-field sustainment; sustainment requirements are defined within the business requirements UCDth017 Reuse of the pre-contract award work for post-contract award development ensured UCDth018 Design coordination and integration of mechanical, electrical, electronics, and embedded software product content UCDth028 Requirements specifications approved, change alerts received, change requests and releases managed UCDth029 Collaboratively defined system architecture and interfaces, merging partners' work products	A, B

Contributor	Digital Thread Title	Description	Lifecycle Stage
Additional Use Cases			
AD PAG	UCDth001: Model-Based Enterprise (MBE)	Enable the enterprise to interact with rich engineering deliverables, to validate products before going into production, and to improve design review efficiency	A, B, C, D, E, F
AD PAG	UCDth002: Lifecycle Bill of Materials (BOM) Management	Complete highly visual product definition driven from Computer-Aided Design (CAD) and other descriptive artifacts for comprehensive configuration management across the product lifecycle	A, B, C, D, E, F
AD PAG	UCDth003: Service and Customer Documentation	Develop technical documentation based directly on digital thread content	B, D, E
AD PAG	UCDth005: Change Impact Assessment	Traceability for synchronization of updates between the digital asset (digital twin) and physical asset(s) to assess cost and lead time impact of change and to mitigate compounding risks of change-on-change	B, C, E
AD PAG	UCDth007: Supply Chain Collaboration	Co-design connectivity across the supply chain for both the product and production	B, C, E
AD PAG	UCDth008: Support Product in Service	Capture, as closely as possible, the state of the product (i.e., configuration, maintenance and repair, operations) to provide adaptive support (malfunction solving, repair solutions, etc.)	D, E, F
AD PAG	UCDth009: Design Optimization and Validation	Closed-loop requirements linking and traceability through design, simulation, prototype, and test	A, B
AD PAG	UCDth010: Model-Based Systems Engineering (MBSE)	Modelling, simulation, and virtual analysis at all stages of the Requirement, Functional, Logical, and Physical (RFLP)	A, B

Contributor	Digital Thread Title	Description	Lifecycle Stage
AD PAG	UCDth011: Bidirectional Traceability	Digital thread ecosystem—Original Equipment Manufacturer - Manufacturing - Supplier (OEM-MFG-Supplier)—for field change impact analysis Connection between early engineering to field support, suppliers, and partners	A, B, C, D, E, F
AD PAG	UCDth012: Final Inspection Before Customer Delivery	Final inspection of Leading-Edge Aviation Propulsion (LEAP) engines based on the configuration As-Planned–As-Built (SAE, Society of Automotive Engineers)	B, C
AD PAG	UCDth013: Manufacturing Execution	Deliver work instructions based directly on digital thread from the Manufacturing Bill of Material (MBOM) down to the shop floor	C
AD PAG	UCDth014: Condition-Based and Predictive Maintenance with Feedback Loops	Traceable linkages that aggregate sensor data, artificial intelligence models, and physics-based reliability models to aid in proactive maintenance and sustainment work **Clarification:** The focus is on the feedback loop to improve the design/definition/performance of the Condition-Based Maintenance (CBM)/Predictive models **Assumption:** Reinjection in the Development Stage (B) closes the loop	B, C, D, E, F
AD PAG	UCDth015: Design Rationale Traceability for Sustainment Decisions	Traceability of design rationale from early conceptual architecture through in-field sustainment Sustainment requirements are defined within the business requirements	A, B, C, D, E, F
AD PAG	UCDth016: Model-Based Repair Publication	Model-based repairs alignment with the technical publication Connect the build and the repair instructions back to the Model-Based Design (MBD)	A, B, E, F
AD PAG	UCDth017: Conceptual Design Traceability to Detailed Design	Accessibility and traceability pre-contract award artifacts to post-contract award development team	A, B

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Contributor	Digital Thread Title	Description	Lifecycle Stage
AD PAG	UCDth018: Cross-Discipline Engineering	Accessibility and traceability of mechanical, electrical, electronics, and embedded software product content to cross-disciplinary engineering teams	A, B
AD PAG	UCDth019: Manufacturing Engineering	Derive plant-specific Manufacturing Bill of Materials (MBOMs) from Engineering Bill of Materials (EBOMs) Derive process plans and work instructions based on the upstream EBOM	B, C
AD PAG	UCDth020: Manufacturing System Certification	Certification of the manufacturing system to the guidelines set by the United States Department of Defense (DoD) Capture data from the manufacturing machines directly and simulate the manufacturing process for certification	B, C
AD PAG	UCDth021: Long-Term Data Archival and Retrieval	Long-term maintenance of data, including archival and retrieval of digital product and technical data Archiving is required until the product's End Of Life (EOL)	E, F
AD PAG	UCDth023: Digital Thread Design Certification	Certification of designs without multiple prototypes; the digital thread facilitates the digital twin design simulations and certification, replacing the need for constructing prototypes A prototype is developed to validate digital twin simulation accuracy and to support the certification process	A, B
AD PAG	UCDth024: Interactive Production and Maintenance	Interact with products based on augmented reality using models and technical documentation	E
AD PAG	UCDth025: Design Optimization Production Capabilities	Consider demonstrated manufacturing capabilities for parts design, including life limitations and inspection plan optimization	A, B, C, D

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Contributor	Digital Thread Title	Description	Lifecycle Stage
SAE	UCDth026: Part Authorized Release Certificate (ARC)	The purpose of an electronic version of the ARC (eARC) is to provide data to civil aviation authorities and accredited organizations issuing or managing airworthiness for new and return-to-service products	C, D, E
AD PAG	UCDth027: End-to-End Planning	Planning data integration across all lifecycle phases in the production phase, from availability of catalog options to delivery, including logistics	A, B, C, D, E
prostep ivip	UCDth028: Collaborative Requirements Content Management	Facilitate the definition and management of requirements within a collaborative distributed supply chain Facilitate requirements approval of requirements specifications, include change alerts, and manage change requests and releases Diagram of this use case (referred to as user journey (UJ1)) is provided below in the notes	A, B
prostep ivip	UCDth029: Collaborative System Design	Collaboratively define the system architecture and interfaces, merging partners' work products	Unlisted
prostep ivip	UCDth030: Distributive Collaborative Co-Simulation	Collaboratively integrate the system model with the partners' sub-systems to simulate, develop, and validate performance; collaborative co-simulation is simulation between two or more partners using two different solvers Scope: • Functional performance simulation, non-geometric (i.e., no finite element modelling (FEM)) • Hardware-in-the-Loop (HIL), Driver-in-the-Loop	A, B, C, D, E, F
prostep ivip	UCDth031: Collaboration Model Setup	Define and set up collaboration models, roles and responsibilities, access rights, information technology (IT) architecture, and archiving models	A

Contributor	Digital Thread Title	Description	Lifecycle Stage
prostep ivip	UCDth032: Collaborative Integration and Tests	Improved integration of components into prototypes and automatic preparation of Hardware-in-the-Loop (HiL) tests	A, B, C
prostep ivip	UCDth033: Collaborative Manufacturing Engineering	Collaboratively define and share data on production process, equipment, and assets	Unlisted

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Demonstrated Use Cases

Write-ups of the demonstrated digital thread use cases are presented in numerical order.

UCDth006: Concession Management

USE CASE NUMBER: UCDth006	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐		
Use Case Owner: AD PAG	**Associated Use Cases:**		
Use Case Title: *Concession Management*			
Description:	As-Built versus As-Designed nonconformities that require Design Office approval (SAE equipment) if concession management means the concessions are back to PLM; frequently, a concession from production is reported as a defect to the Customer Service Center and is later determined to be a false positive		
Goal:	Decrease the frequency of false positives		
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☐		
Use Case Frequency:	Daily ☐ Weekly ☒ Monthly ☐ Yearly ☐ Other ☐		
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐		
Roles:	Airline Representatives, Engine Customer Service Center (CSC) Employees, Engine Aftersales Design Office		
Preconditions:	A finding on an engine by an airline representative		
Normal Course of Events:		**Action:**	**Result:**
	1.	Airline representative contacts Engine CSC about a finding related to a part	CSC employee contacts the Engine Aftersales Design office about the finding; the engine may be grounded for the investigation time
	2.	Engine Aftersales Design Office investigates the finding	If the finding is a false-positive, it is a production concession that has been already cleared at production. CSC Employee is notified after a possibly long delay
	3.	CSC Employee returns to the airline representative to close the case	Engine is released, but product satisfaction is lost
Alternate Course(s) of Events:	Due to the digital thread, the CSC Employee can check if the finding results from a production concession; If it does, the CSC Employee can then provide a quick answer to the customer without overloading the design office		

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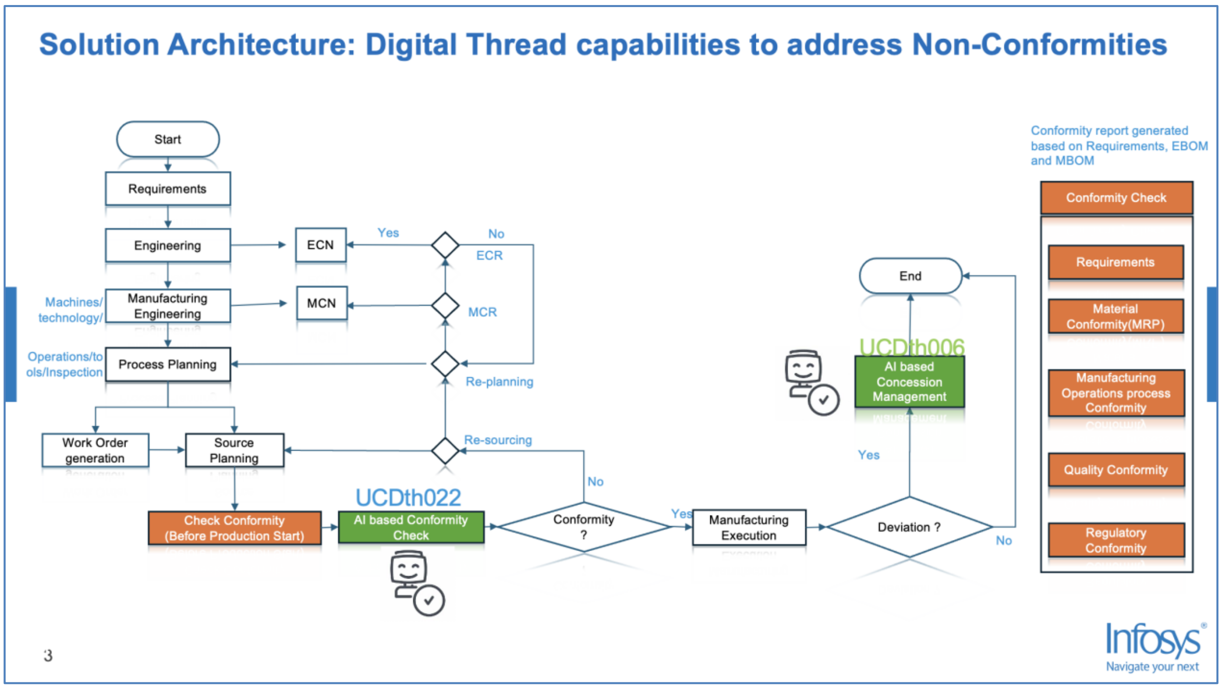
Data:	None
Postconditions:	None
Notes:	This use case is also helpful for aftersales. Engine Aftersales Design Offices are overwhelmed by questions, and the answer rate can be excessive for airlines; the office should only be solicited for important technical questions

UCDth022: Production and Support: AI-Enhanced PLM-MES Integration for Manufacturing Conformance Management

USE CASE NUMBER: UCDth022	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐		
Use Case Owner: AD PAG (Infosys Demo)	**Associated Use Cases:**		
Use Case Title: *Production and Support: AI-Enhanced PLM-MES Integration for Manufacturing Conformance Management*			
Description:	Native digital data traceability from Product Lifecycle System (PLS) As-Designed to recording in the Manufacturing Engineering System (MES) during production operations to confirm conformity before delivery		
Goal:	Enable traceability of As-Designed data to MES data records		
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☒ F-Retirement ☐		
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ On-demand related to product lifecycle activity		
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐		
Roles:	Digital Thread Architect, System Engineer, Design Engineer, Product Quality Engineer, Support/Service Engineer, Custom Support Engineer		
Preconditions:	Defined digital thread architecture		
Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	Customer requirement is received	Design requirements are prepared
	2.	Product/Solution is engineered	Product sustainability solution is engineered

	3.	Engineering requirement is received, and digital thread is defined	Digital thread requirements are defined
	4.	Digital thread definition is designed	Product digital thread is defined
	5.	Product support digital thread solution is defined	Product support digital thread solution is implemented
Alternate Course(s) of Events:	Customer service request utilizes the digital thread to access design and manufacture design data		
Data:			
Postconditions:	None		
Notes:			



UCDth035: Collaborative System Engineering

USE CASE NUMBER: UCDth035	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: Hexagon	**Associated Use Cases:**
Use Case Title: *Collaborative System Engineering*	
Description:	Connecting design and simulation engineers onto the same 3D system model, allowing faster design optimization iterations in real time

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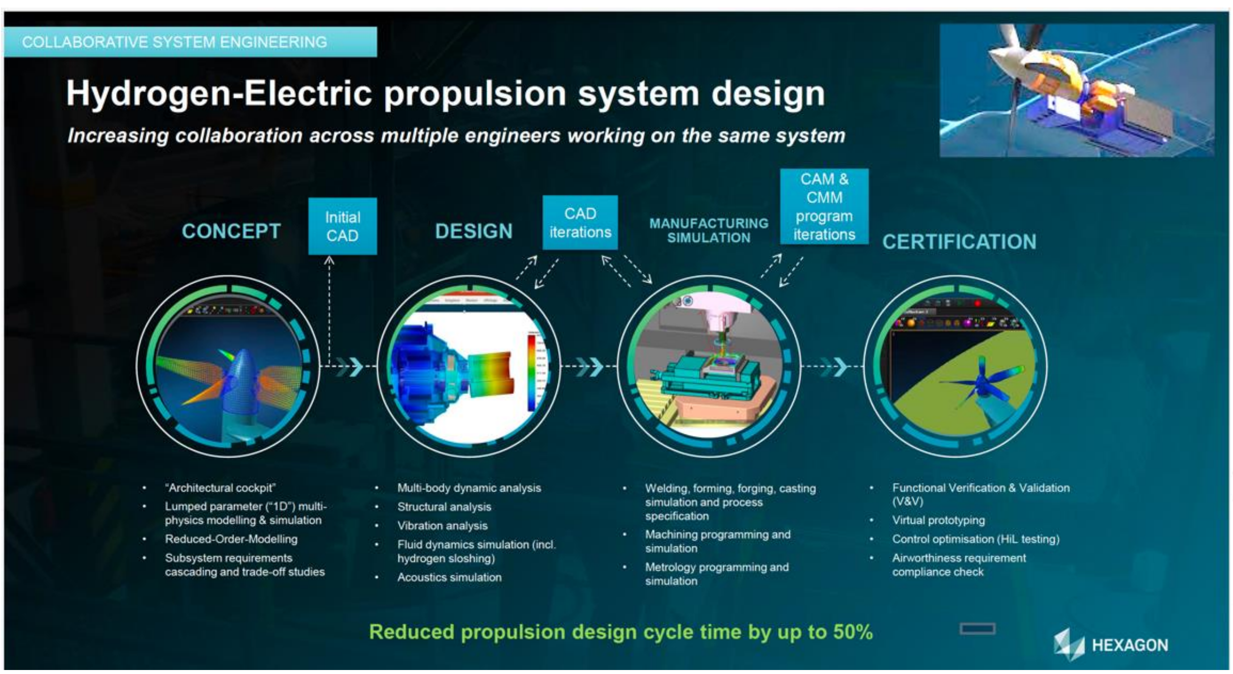
Goal:	Reduce design cycle time
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☒ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	IT Engineer, Design Manager, Design Engineer, Simulation Engineer, System Engineer
Preconditions:	Existing and maintained 3D model of the designed system

Normal Course of Events:

	Action:	Result:
1.	**Concept preparation:** • "Architectural cockpit" • Lumped parameter ("1D") multi-physics modelling and simulation • Reduced-Order-Modelling • Subsystem requirements cascading and trade-off studies	Initial CAD work done Increased collaboration across multiple engineers working on the same system
2.	**Design preparation:** • Multi-body dynamic analysis • Structural analysis • Vibration analysis • Fluid dynamics simulation, including hydrogen sloshing • Acoustics simulation	CAD iterations made as needed Increased collaboration across multiple engineers working on the same system

	3.	**Manufacturing simulation:** • Welding, forming, forging, casting simulation and process specification • Machining programming and simulation • Metrology programming and simulation	CAD iterations made for both design and manufacturing simulation as needed CAM and CMM program iterations made as needed Increased collaboration across multiple engineers working on the same system
	4.	**Certification:** • Functional Verification and Validation (V&V) • Virtual prototyping • Control optimization, hardware-in-the-loop (HiL) testing • Airworthiness requirement compliance check	Design is certified within a reduced design cycle time (up to 50%) due to increased collaboration across multiple engineers working on the same system
Data:	3D Design and Simulation Data		

Notes:



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UCDth036: End2End Additive Manufacturing

USE CASE NUMBER: UCDth036	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐		
Use Case Owner: Hexagon	**Associated Use Cases:**		
Use Case Title: *End2End Additive Manufacturing*			
Description:	Connecting component CAD data with 3D printing machine data and metrology (quality control) machines to enable a virtuous data loop allowing to automatically refine machine parameters and component design based on an advanced quality-controlled process		
Goal:	Ensure faster design and manufacturing iteration loops and a repeatable process for additive manufactured components		
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐		
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☒ Yearly ☐ Other ☐		
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐		
Roles:	IT Engineer, CAD Design Engineer, Additive M and Metrology Engineer, Production Manager, Additive M Engineer, CNC Operator, Quality Inspector, Manufacturing Manager		
Preconditions:	Existing and maintained 3D model of the designed system		
Normal Course of Events:		**Action:**	**Result:**
	1.	**Product design:** • Scan to CAD or Generative Design • Topology optimization based on performance and manufacturability (Design for Additive Manufacturing (DfAM)) • Computer-aided engineering (CAE) analysis, including static and dynamic structural simulation	Nominal CAD to PLM

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	2.	**Process engineering:** • Component preparation (machining allowance, etc.) • Printing direction optimization • Support structure generation • Nesting • Printing strategy	Engineering processes defined, optimized, and applied
	3.	**Manufacturing simulation:** • Manufacturing process simulation, including heat treatment and post-treatment operations: – Defect prediction – Manufacturing issues mitigation – Distortion compensation • Post-treatment computer numerical control (CNC) machining preparation and simulation • 3D printer and CNC toolpath generation	Machine code and parameters to manufacturing execution system (MES) Improved part performance and manufacturability and reduced CO_2 emissions
	4.	Manufacturing	Product manufactured
	5.	**Component inspection:** • Dimensional inspection • Quality inspection – computed tomography (CT) analysis / nondestructive evaluation (NDE) • Quality control reporting and export • Post-treatment analysis, including statistical trend analysis • Non-conformity case creation and tracking, if any	Inspections conducted Quality reports provided to the quality management system (QMS) Sustainability objectives met
Data:	Nominal CAD, 3D Printing Machine Parameters, CNC Machine Data, Metrology Equipment Data		

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Notes:

UCDth038: Virtual Assembly

USE CASE NUMBER: UCDth038	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: Hexagon	**Associated Use Cases:**
Use Case Title: *Virtual Assembly*	
Description:	Using 3D geometry data of the real parts being manufactured to virtually predict the compliance of next assembly system; and subsequent corrective actions needed if not compliant
Goal:	Predict large/complex assembly issues and rework components proactively
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☒ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐

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Roles:	IT Engineer, CAD Design Engineer, Metal Forming Engineer, Metrology Engineer, Production Manager, Assembly Operator, Quality Inspector, Manufacturing Maager		
Preconditions:	Continuous 3D scanning of manufacturing parts		
Normal Course of Events:		**Action:**	**Result:**
	1.	Component or sub-assembly received from the supplier **3D capture:** • Geometrical assembly requirements collection • Fuselage non-contact 3D scanning • 3D data cloud meshing and preparation	Nominal CAD from PLM 3D capture of the component or sub-assembly
	2.	**Virtual jig and assembly:** • Reduced order modelling • 3D data morphing and compensation • Real versus Nominal data correlation • Assembly process specification • OK/NOK assembly compliance report	Optimized CAD from PLM Assembly compliance report to manufacturing execution system (MES)
	3.	**Correction:** • Best rework option suggestion • Rework (grinding or shimming) calculation and simulation • Corrected tool path generation • Metrology-assisted manufacturing and inspection	Corrected code to MES Corrected machine code to the shop floor (return to step2, virtual jig and and assembly)
	4.	**Quality reporting:** • Data collection and measurement report generation • Quality report recording and export • Post treatment analysis (SPC) • Non-conformity case creation and tracking, if any	Quality reports provided to the quality management system (QMS) Sustainability objective met – reduced inspection cost by up to 75%

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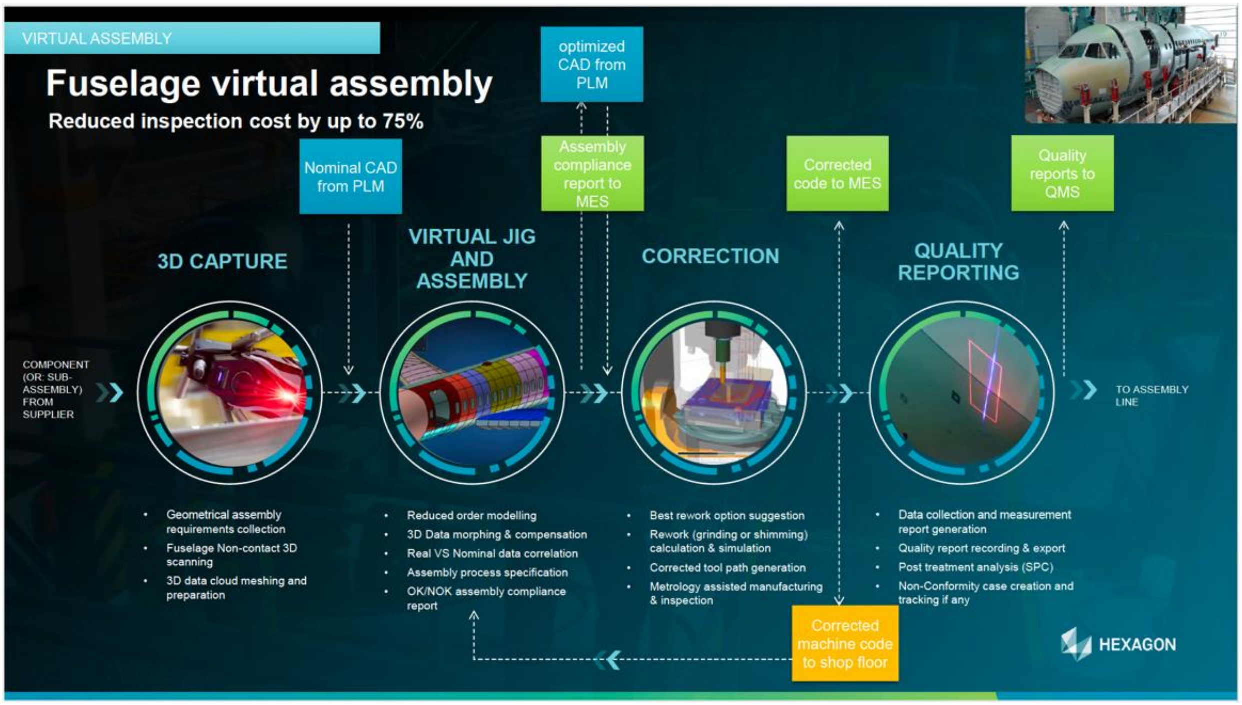
Data:	Nominal CAD, Real Manufactured Geometry Data of the Elementary Parts and Assembly System
Notes:	



UCDth039: Digital Thread End-to-End Automated Inspection

USE CASE NUMBER: UCDth039	**Use Case Type: Digital Thread** ☒	**Digital Twin** ☐
Use Case Owner: Hexagon	**Associated Use Cases:**	
Use Case Title: *Digital Thread End-to-End Automated Inspection*		

Description:	Connecting quality reports along the manufacturing process with manufacturing process data to enable process deviation and out of tolerance issues as soon as possible (ASAP) and provide guidance to correct the process
Goal:	Reduce scrap rate and increase productivity
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☒ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐

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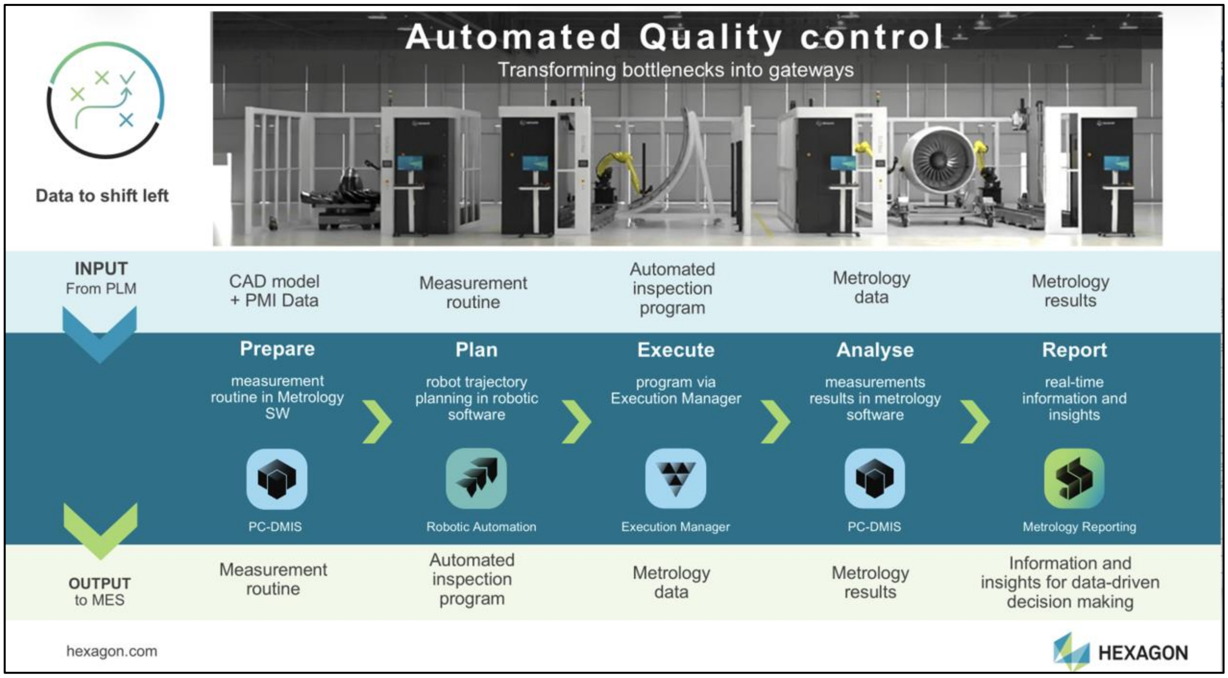
<table>
<tr><td>Roles:</td><td colspan="3">IT Engineer, CAD Design Engineer, Manufacturing Engineer, Quality Engineer, Manufacturing and Quality Manager, Quality Inspector, Manufacturing Manager</td></tr>
<tr><td rowspan="5">Normal Course of Events:</td><td></td><td>Action:</td><td>Result:</td></tr>
<tr><td>1.</td><td>Nominal CAD from PLM

Importing CAD:
• Component 3D model import & balancing
• Dimensional requirements preparation</td><td>CAD imported</td></tr>
<tr><td>2.</td><td>Programming:
• Inspection sensor auto-configuration
• Robot tool path generation</td><td>Inspection program to manufacturing execution system (MES)</td></tr>
<tr><td>3.</td><td>Inspection:
• Component identification and tracking
• Robot and sensors calibration
• 3D non-contact scanning</td><td>Inspections performed for reporting</td></tr>
<tr><td>4.</td><td>Reporting:
• Data collection and measurement report generation
• Quality report recording and export
• Post-treatment analysis, including statistical trend analysis
• Non-conformity case creation and tracking, if any</td><td>Quality reports provided to the quality management system (QMS)

Increased productivity and reduced need for skilled operators

Reduced inspection cost by up to 75%</td></tr>
<tr><td>Data:</td><td colspan="3">Nominal CAD, Manufacturing Process Data, Metrology Equipment Data</td></tr>
</table>

Notes:
 **Hexagon Automated Quality Control**

UCDth044: Solution Architecture Model

USE CASE NUMBER: UCDth044	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐	
Use Case Owner: Capgemini	**Associated Use Cases:**	
Use Case Title: *Solution Architecture Model*		
Description:	Showcase how a solution architecture framework (Figure 1) in a modeling tool such as DS CATIA Magic (formerly No Magic Cameo) can enhance collaborative model-based practices across an organization by connecting digital thread use cases to the technical solution	
Goal:	Improve decision-making, traceability, and communication among diverse stakeholders, while streamlining complex solution development and facilitating digital engineering implementation into the organization	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐	
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Continuous utilization – On demand	
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐	

↑ View Digital Twin List ↑ View Digital Thread List

<table>
<tr><td>Roles:</td><td colspan="3">Strategic Decisionmakers (e.g., Executives and Organizational Leaders); Program Managers and Certifiers (overseeing project execution); Technical Professionals, including Business Analysts, Solution Architects, Engineers, and Developers (responsible for design and implementation)</td></tr>
<tr><td>Preconditions:</td><td colspan="3">Facing challenges in managing digital solution development, which necessitates a more integrated approach to solution architecture due to the following:
Growing demand for digital engineering practices and model-based systems engineering (MBSE) require a more complex digital ecosystem to enable the digital thread
Needing a common language and semantically meaningful information metamodel to support effective digital engineering across the organization
Seeking a more streamlined solution development with improved trade-off analysis capability for solution benchmarking</td></tr>
<tr><td>Special Requirements:</td><td colspan="3">None</td></tr>
<tr><td rowspan="8">Normal Course of Events:</td><td></td><td>Action:</td><td>Result:</td></tr>
<tr><td>1.</td><td>Initiate the project and define the scope and objectives</td><td>Architecture vision and scope is created</td></tr>
<tr><td>2.</td><td>Elicit the requirements</td><td>Requirements specification document is completed</td></tr>
<tr><td>3.</td><td>Capture the baseline scenario</td><td>As-Is architecture model is created</td></tr>
<tr><td>4.</td><td>Define the desired capabilities and features</td><td>Capability and features are defined and traced to the requirements</td></tr>
<tr><td>5.</td><td>Define the target scenario</td><td>To-Be architecture model is specified</td></tr>
<tr><td>6.</td><td>Perform gap analysis</td><td>Gap analysis report is generated, and areas for improvement are identified</td></tr>
<tr><td>7.</td><td>Define the roadmap and implementation plan</td><td>Architecture roadmap and implementation plan are documented and approved</td></tr>
<tr><td>Alternate Course(s) of Events:</td><td colspan="3">Iterative refinement of the architecture model based on stakeholder feedback or changing business priorities
Integration of new technologies or systems which may require updates to the architecture model</td></tr>
<tr><td>Data:</td><td colspan="3">See Metamodel image (Figure 2) in the Notes section</td></tr>
<tr><td>Postconditions:</td><td colspan="3">Solution architecture model is accessible to relevant stakeholders</td></tr>
</table>

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Notes:

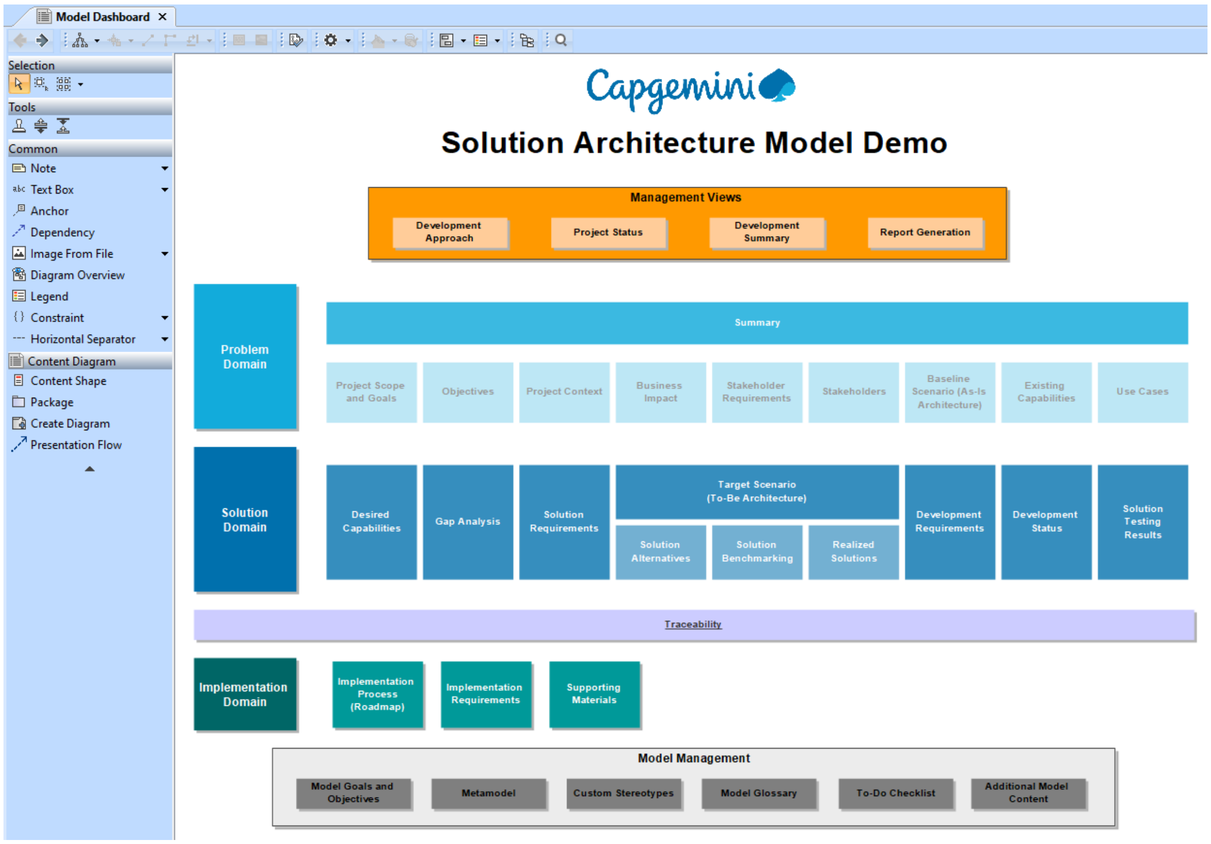


Figure 1 - Solution Model Demo Overview

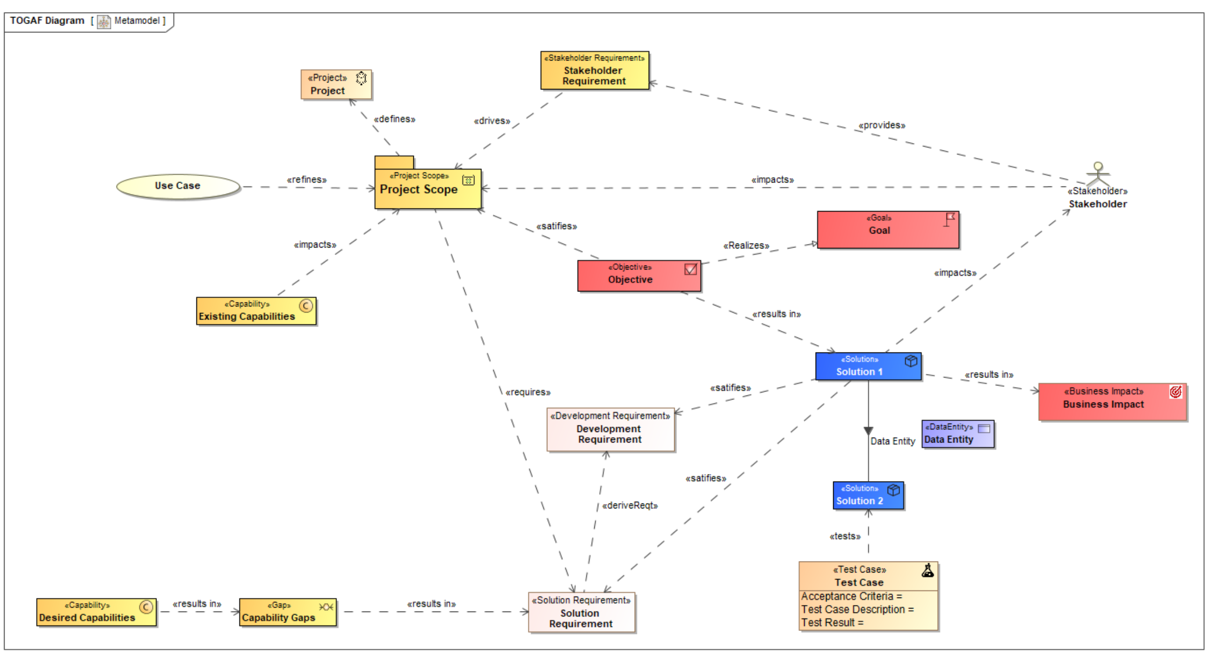


Figure 2 - Solution Architecture Metamodel

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UCDth049: A Day in the Life of Data Workers with an Automated Digital Thread

USE CASE NUMBER: UCDth049	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: eQ Technologic	**Associated Use Cases:** UCDth001, UCDth002, UCDth009, UCDth010, UCDth022, UCDth027, UCDth028, UCDth033
Use Case Title: *A Day in the Life of Data Workers with an Automated Digital Thread*	
Description:	eQube®-DaaS (Data as a Service) coupled with the eQube-DTA (Digital Thread Application) provides an integrated data fabric stitching data, applications, and devices through all the phases of a product development lifecycle while honoring data security, maintaining digital thread (DT) configuration management, and providing user search and navigation on a single screen; this solution results in dramatic improvements in productivity, quality, and unparalleled insights and access to data within and between the enterprise systems This use case "walks" through a day in the life of an integrated digital product development environment and demonstrates the automated creation and maintenance of a digital fabric with configuration-controlled DTs across Commercial off-the-shelf (COTS), Government off-the-shelf (GOTS), and internally developed enterprise applications while honoring the data security models within each of these applications eQ-Technologic will show the integration of data between Jira, DOORS NextGeneration, Capella, Minerva, Windchill, SAP, and Solumina The eQube-DaaS platform and eQube-DTA are designed to be future-proof, system agnostic, and are built to enable adding, removing, and changing applications through the life of the product, allowing customers to incorporate new technologies as required
Goal:	Provide the following to user(s) having different roles and needs: 1. Ability to create, maintain, and navigate a configuration-controlled digital fabric and threads 2. Automated data replication according to business logic between enterprise software systems using eQube-DaaS APIs, utilizing actions within that software, enabling end users to stay in the systems with which they are already familiar 3. Automatically populate and update the digital fabric with data from enterprise applications 4. Ability to create digital stitches between applications automatically 5. An accelerated path to data discovery to visualize related enterprise data with minimal training 6. A configuration-controlled thread that can be baselined (released) for assessment and disposition of enterprise-wide changes to the product 7. A single, user-friendly, and intuitive interface to view and navigate threads showing objects from multiple applications with different data models, architectures, and security 8. Ability to view, analyze, track, and maintain a digital thread in a simple-to-use, single-view, zero-client web app

↑ View Digital Twin List ↑ View Digital Thread List

Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒
Use Case Frequency:	Daily ☒ Weekly ☒ Monthly ☒ Yearly ☒ Other ☒
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒
Roles:	In order of the course of events: • Program/Project Manager • Requirements Engineer • System Engineer • Simulation/Design Engineer • Mechanical/Manufacturing Engineer • Process Planner
Preconditions:	Enterprise applications (Jira, DOORS-NG, Capella, Minerva, and Windchill) configured to meet the business processes of our Roles, which will trigger eQube-DaaS Application Programming Interfaces (APIs) via context menus and other actions

Normal Course of Events:

	Action:	Result:
1.	**Plan Creation in Jira:** Program/Project Manager creates a plan in Jira consisting of five Jira stories: Requirement Definition, System Modelling, System Simulation, Mechanical Design, and Process Planning	An eQube-DaaS API is triggered with no user action other than creating the stories in Jira eQube populates a Digital Fabric Persistence Database (a graph database), which creates the automated digital fabric viewed by the user(s) as a digital thread; this fabric and its threads are visible in a digital thread app (eQube-DTA)
2.	Program Manager releases the digital thread	
3.	**Requirement Definition:** Program/Project Manager assigns a Requirements Engineer to the Requirement Definition Jira story	Jira notifies the Requirements Engineer

	4.	Requirements Engineer opens the Jira story, marks it as In Progress, and navigates to the DOORS-NG module Within DOORS-NG, the Requirements Engineer finds the requirement specification Requirements Engineer can open eQube-DTA and see the current digital thread across DOORS-NG and JIRA in a single view, providing insight on activities to initiate collaboration as needed across the program team	eQube-DaaS automatically generates a DOORS-NG module for the Requirements Engineer and associates the module to the digital fabric eQube-DaaS places a link in the digital fabric, viewable from eQube-DTA, to both the Jira story and the DOORS-NG module; this automation assures the digital fabric is useful and maintained without user intervention Requirement specification is created within DOORS-NG; the DOORS-NG module is now associated with specific requirements in the digital thread
	5.	Requirements Engineer transfers the DOORS-NG requirements to Capella for Systems Engineering to develop and associate a systems model and relate to the requirements model This uses an eQ automation configured to run from a drag-and-drop between DOORS-NG and the Capella package eQube dialog box allows the Requirements Engineer to associate the Requirement Definition Jira story to this action These actions simplify the user experience across enterprise applications	On drop in Capella, eQube-DaaS automatically fetches the selected specification and requirements from DOORS-NG and creates a package in Capella for the requirement specification and all its requirements Requirement specification and the requirements are added to the digital thread; in this action, it was decided that DOORS-NG objects needed to be replicated, allowing the Systems Engineer within Capella to derive, associate, and satisfy requirements within the Capella application eQube updates the Digital Fabric Persistence Database with these objects and relationships in the background, extending and maintaining the digital fabric and thread without human intervention
	6.	Requirements Engineer closes the Requirement Definition Jira story	
	7.	Program/Project Manager reviews and accepts the changes to their digital thread	
	8.	**System Modelling:** Program/Project Manager assigns the System Modelling Jira story to a System Engineer	Jira notifies the System Engineer

	9.	System Engineer opens the Jira story, marks it as In Progress, and opens Capella System Engineer then creates derived engineering requirements for the system model, using the requirements eQube-DaaS automatically synchronized from DOORS-NG in step 4, saving time and reducing errors System Engineer assigns these derived requirements to a Capella Block by applying the Satisfy relationship, then saves the updates	System model engineering requirements are created in Capella
	10.	System Engineer uses Capella to select the top-level block and executes a sync using an eQIntegrator context menu, responding to the eQube dialog box to associate the Jira story to this action	eQube API is called to insert the Capella requirements and block into the digital thread, relating them to the requirements in DOORS-NG already present A Project Manager can see the resulting engineering model traced back through the requirements and Jira stories using eQube-DTA to visualize this digital thread
	11.	System Engineer closes the System Modelling Jira story	
	12.	Program/Project Manager reviews and accepts the changes to their digital thread	
	13.	**System Simulation:** Program/Project Manager assigns the System Simulation Jira story to the Simulation/Design Engineer	Jira notifies the Simulation/Design Engineer
	14.	Simulation/Design Engineer opens the Jira story, marks it as In Progress, and opens Capella Simulation/Design Engineer then initiates the simulation run by selecting the top-level design block and executing a simulation workflow using the eQIntegrator context menu, responding to the eQube dialog box to associate the Jira story to this action	An eQube API is called that creates the work request in Minerva, assigns users, adds the top-level design block URL to Minerva, updates the Jira ticket with the Minerva work request URL, and updates the digital thread eQ has automated adding links between Jira and Minerva to save time in this critical simulation step

	15.	In Jira, the Simulation/Design Engineer clicks the work request URL created in step 14, then completes the assigned tasks to the work request, attaching a simulation results file in Minerva Simulation/Design Engineer may now open eQube-DTA to view the requirements driving the simulation	eQube-DaaS automatically downloads the simulation results from Minerva, uploads the simulation files to a filesystem, and provides a link inside Capella to this simulation file eQube-DaaS updates the digital fabric to show the simulation files stitched to their Capella blocks, DOORS-NG requirements, and Jira story These stitches allow a user to quickly navigate between related objects using eQube-DTA or the enterprise applications
	16.	Simulation/Design Engineer closes the System Simulation Jira story	
	17.	Program/Project Manager reviews and accepts the changes to their digital thread and saves a copy of the thread as “System Design Review”	
	18.	**Mechanical Design:** Program/Project Manager assigns the Mechanical Design Jira story to a Mechanical Engineer	Jira notifies the Mechanical Engineer
	19.	Mechanical Engineer opens the Jira story, marks it as In Progress, and opens Capella Mechanical Engineer then initiates a transfer of this data to the Windchill PLM system by selecting the parent block, executing a sync using the eQIntegrator context menu, and responding to the eQube dialog box to associate a Jira story to this action eQube-DTA can now run an impact analysis showing the entities which drove this Windchill part creation	An eQube API is called that creates parts and assemblies in Windchill and updates the digital thread This prevents the Mechanical Engineer from having to manually create parts in Windchill that match with the System Engineer design, saving time and increasing accuracy eQube-DTA shows stitches relating the Capella systems model to the Windchill parts, allowing the Mechanical Engineer to quickly navigate between the objects
	20.	Mechanical Engineer designs the parts and configures an assembly in Windchill	Parts and assemblies are configured in Windchill
	21.	Mechanical Engineer closes the Mechanical Design Jira story	

↑ **View Digital Twin List** ↑ **View Digital Thread List**

	22.	Program/Project Manager reviews and accepts the changes to their digital thread	
	23.	**Process Planning:** Program/Project Manager assigns the Process Planning Jira story to the Process Planner Process Planner opens the Jira story, marks it as In Progress, and opens Windchill	Jira notifies the Process Planner
	24.	In Windchill, the Process Planner drags the assemblies and parts (created in step 19) onto the structure view of the Process Plan in Windchill	Process Plan with parts is created in Windchill
	25.	Process Planner uses the eQIntegrator menu tab to sync the Process Plan to Solumina and then responds to the eQube prompt to associate a Jira story to this action	An eQube API is called that creates the BOM and Process Plan in Solumina and creates Material Master entries in SAP The digital thread is updated, showing the entire fabric from initial project creation to manufacturing and procurement, with all associated entities automatically created without user input
	26.	Process Planner closes the Process Planning Jira story	
	27.	Program/Project Manager reviews and accepts the changes to their digital thread and saves a copy of the thread as "Product Design Review"	
Data:			
Postconditions:	As the business processes for project creation progress, eQube-DaaS replicates data between ASoT systems both as automated processes and by user input. When data flows through eQube-DaaS, a digital fabric is created automatically from Authoritative Source of Truth (ASoT) objects and their relationships; as the digital fabric is created, digital threads are created by the Program Manager for use inside eQube-DTA		

Notes:	**Definitions:** • **eQube-DaaS** "Data as a Service" platform which integrates data across enterprise applications via robust, configuration-controlled APIs and processes; includes the eQube applications, including eQube-BI (Business Intelligence) and eQube-MI (Migration and Integration) • **Digital Fabric** The interconnected graph database which captures objects, relationships, and relationship types within and between ASoTs, created while data flows through the eQube-DaaS digital backbone • **Digital Thread** Live report of the digital fabric with specific objects and relationships and a defined starting point; useful for a specific user persona and role; configuration-controlled, tailorable, configurable, and editable • **Stitch** A single link between two ASoTs that shows the relationship between two entities and allows the user to navigate between them

UCDth050: Digital Engineering Certification Solution (DECS)

USE CASE NUMBER: UCDth050	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: Capgemini	**Associated Use Cases:**
Use Case Title: *Digital Engineering Certification Solution (DECS)*	
Description:	Accelerating the digital aircraft certification process within a comprehensive tool landscape, including a digital ledger
Goal:	Enhance data traceability and data integrity for a transparent audit trail
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Continuous utilization – On demand
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	All enterprise roles involved in aircraft certification, such as Head of Design, Head of Office of Airworthiness (HOA), Design Engineer, Systems Engineer, Head of Design Organization (HDO), Head of Design, Head of Independent System Monitoring (HISM), Compliance Verification Engineer (CVE), Designated Engineering Representative (DER), Chief Test Engineer, Quality Assurance, Test Engineers

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Preconditions:	• Design organization has a regulatory demand for improved data traceability and integrity during the aircraft certification process • Need for type certification, manufacturing certification, and part certification demands thorough traceability of the origin, the association of executed means of compliance to certification requirements and use cases, and a secure way to share certification data across the extended enterprise
Special Requirements:	None

Normal Course of Events:		**Action:**	**Result:**
	1.	Identify regulatory requirements	Certification specification and use cases are modelled in Model-Based Systems Engineering (MBSE)
	2.	Select validation strategies	Applicable means of compliance (MOC) for each use case is selected
	3.	Create validation plans	Test plans and test cases are created
	4.	Define validation task(s)	Tasks in a Task Management Tool and test script(s) are assigned to the responsible engineers
	5.	Perform engineering analysis and testing	Analysis and test results are made part of test reports (see Figure 1 for example responsibilities)
	6.	Conduct compliance checking and visualization	Validation summary (VS) is prepared
	7.	Create the accomplishment summary	Certification documentation is prepared (traceability and provenance according to Figure 2)

Alternate Course(s) of Events:	Process might differ depending on the specific type of certification (e.g., CS-23 versus CS-27) and the interaction with regulatory agencies (e.g., FAA versus EASA).
Data:	See DECS Demo Architecture illustration (Figure 3)
Postconditions:	None
Notes:	

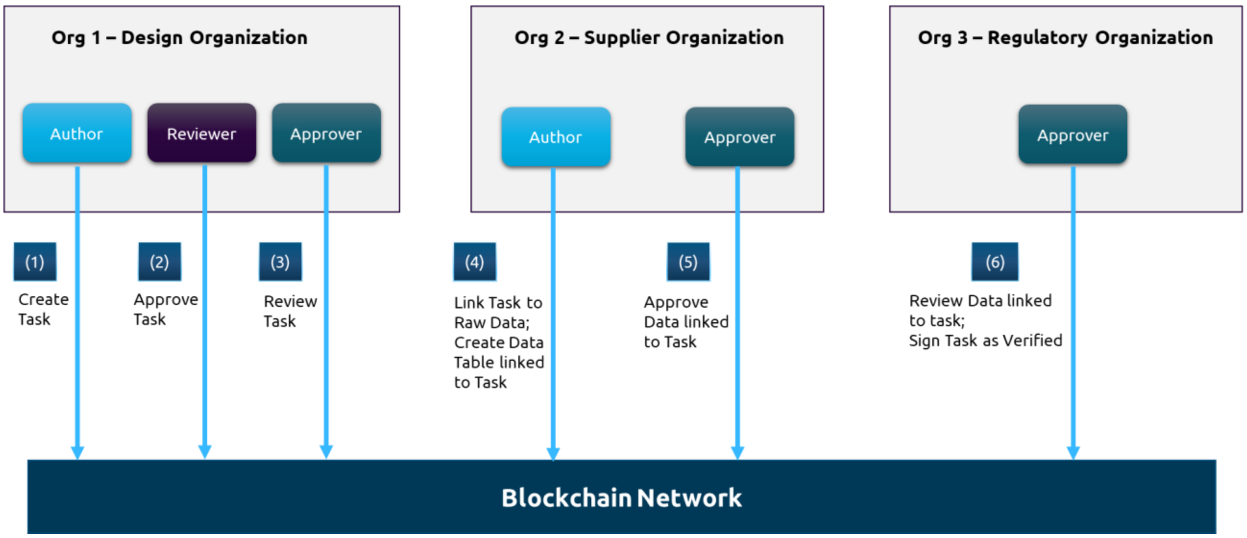

Figure 1 - Robust Data Transparency as an Enabler for Secure Extended Enterprise Cooperation

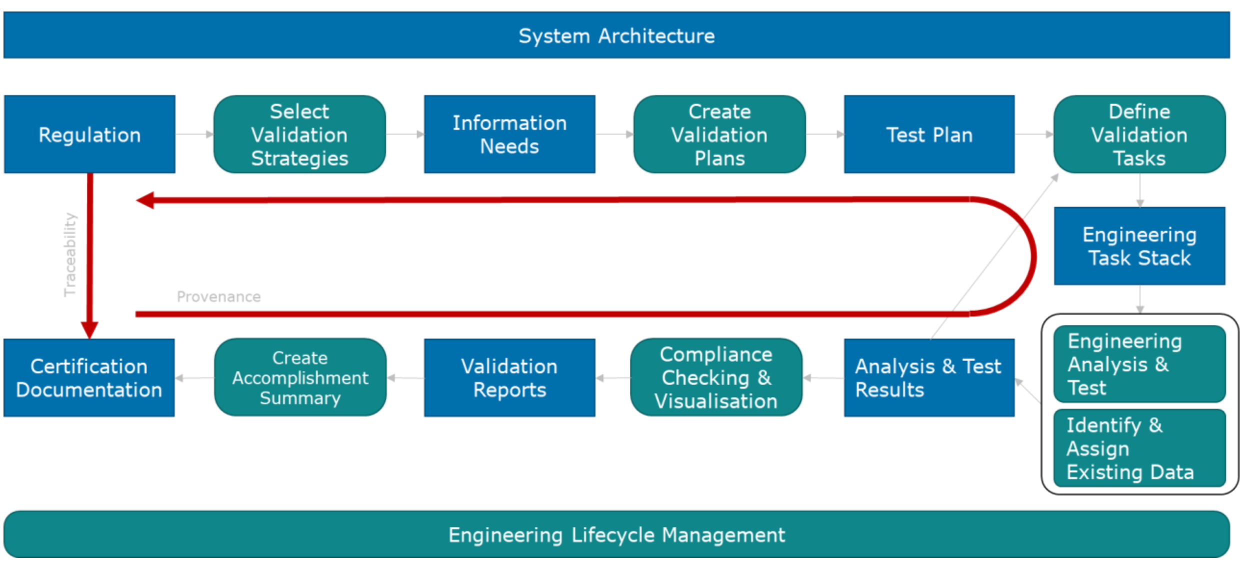

Figure 2 - Digital Certification Vision

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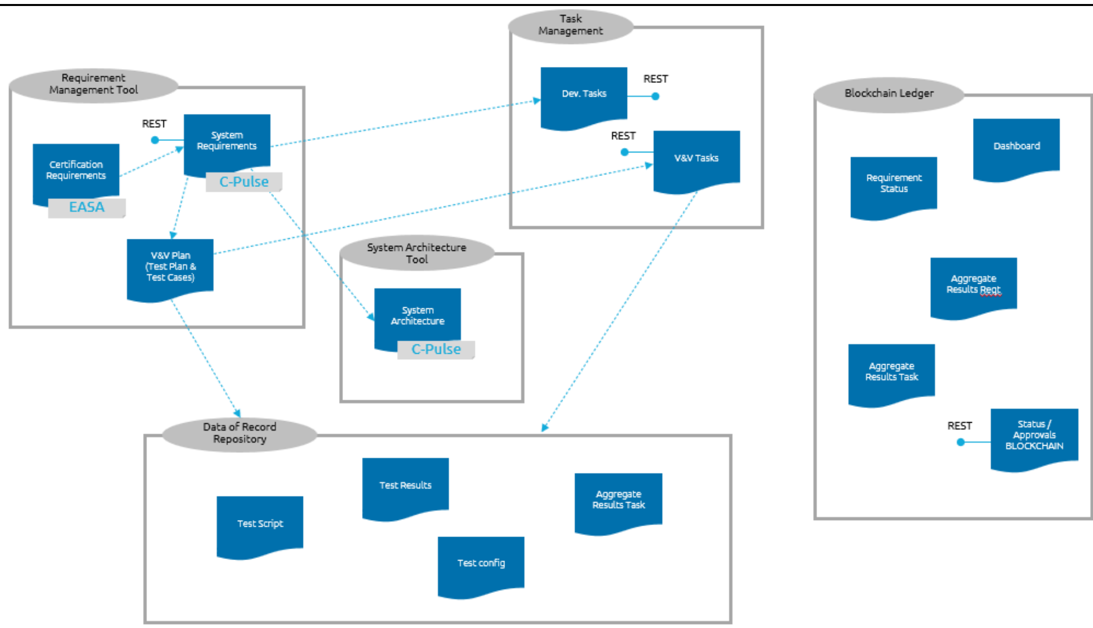


Figure 3 - DECS Demo Architecture

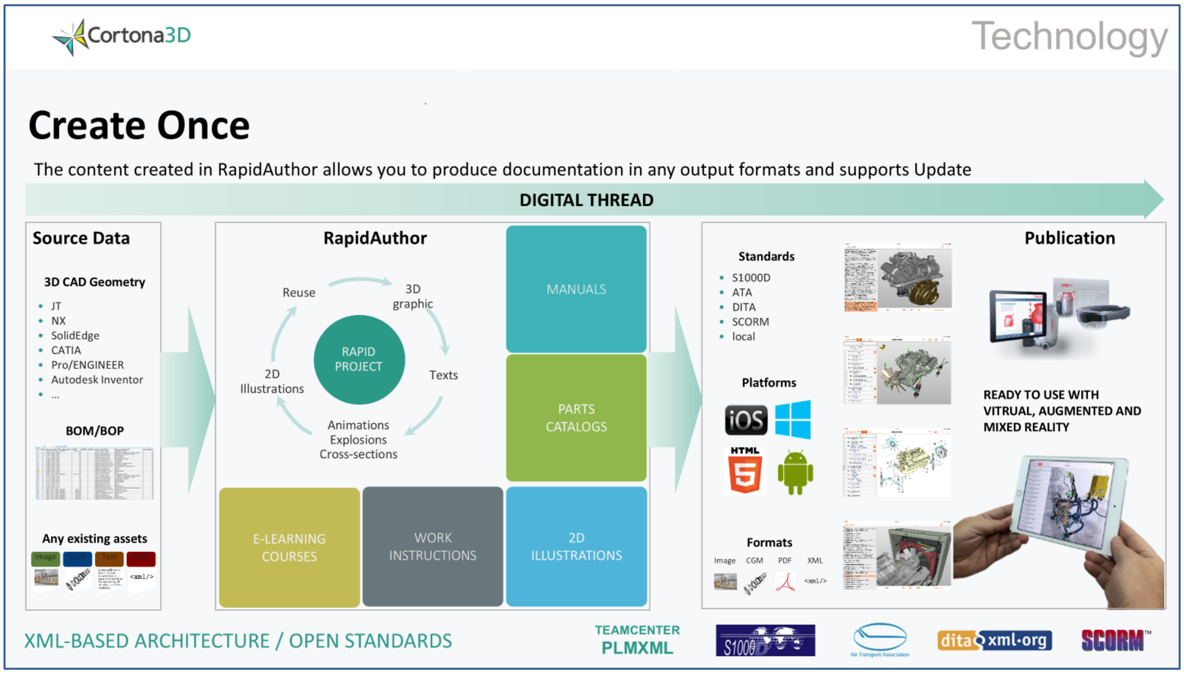
UCDth051: Technical Documentation in the Digital Thread

USE CASE NUMBER: UCDth051	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: Cortona3D	**Associated Use Cases:** UCDth003, UCDth013, UCDth016
Use Case Title: *Technical Documentation in the Digital Thread*	
Description:	Develop technical documentation based directly on product data for manufacturing and service
Goal:	Semi- or fully automatic generation of the entire documentation, including animations, from a single source of truth (SSOT) in the PLM system
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Roles:	Technical Author (creator of the technical documentation), Service Technician, Manufacturing Engineer (user of the technical documentation)
Preconditions:	Design/engineering data available as CAD in the PLM system or locally

↑ **View Digital Twin List** ↑ **View Digital Thread List**

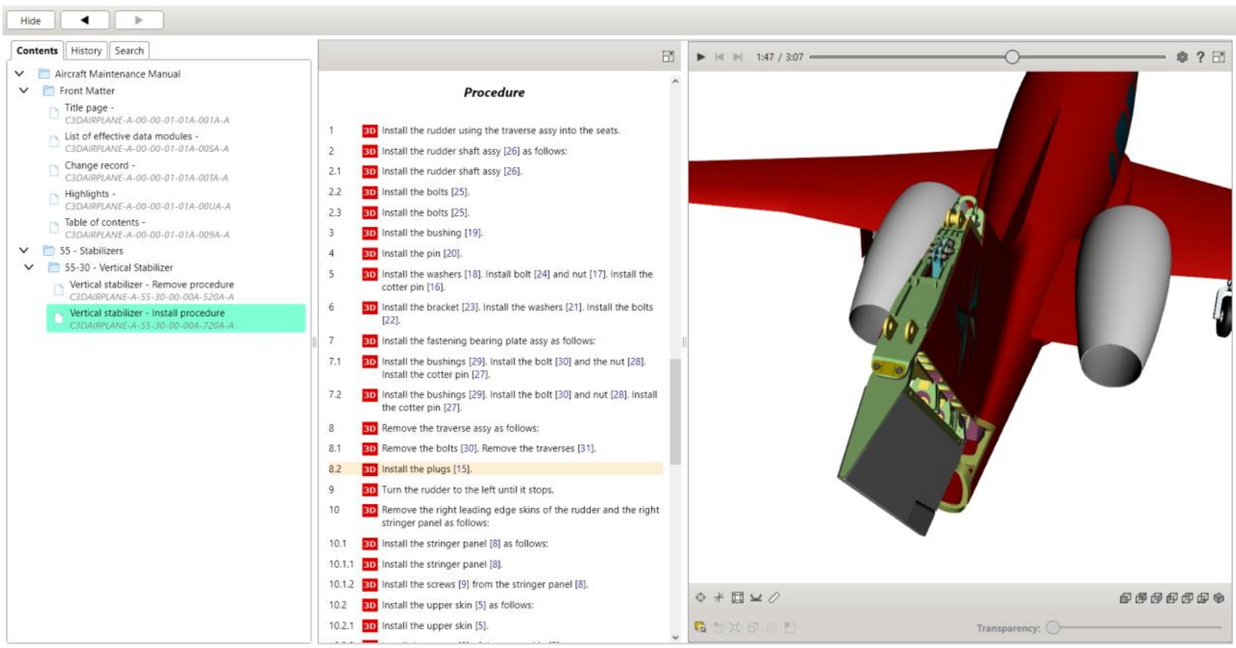
Normal Course of Events:		**Action:**	**Result:**
	1.	CAD data (and other available information about the procedure) is imported from the PLM system (or local disk)	CAD data is converted to lightweight, not reverse-engineerable 3D data
	2.	Technical Author makes use of the advanced automation features to quickly create parts catalogs, learning courses, manuals, or work instructions that all make use of the imported information	After creation, the documents are published, and the project as well as the published documentation is saved back to the PLM system Everything is based on a SSOT in the PLM system, and all artifacts stay as part of the product lifecycle; all of them can be tracked, versioned, updated, and localized The documentation becomes part of the product
	3.	An update or a different variant of the CAD data exists, and the Technical Author updates the existing project with this new data	Design changes are recognized, allowing for an automatic update of the whole documentation
	4.	An advanced integration tool (e.g., Service Planner, Manufacturing Process Planner, Easy Plan) is set up	The integration tool allows fully automatic generation of the whole documentation, including animations, from this SSOT
Data:			

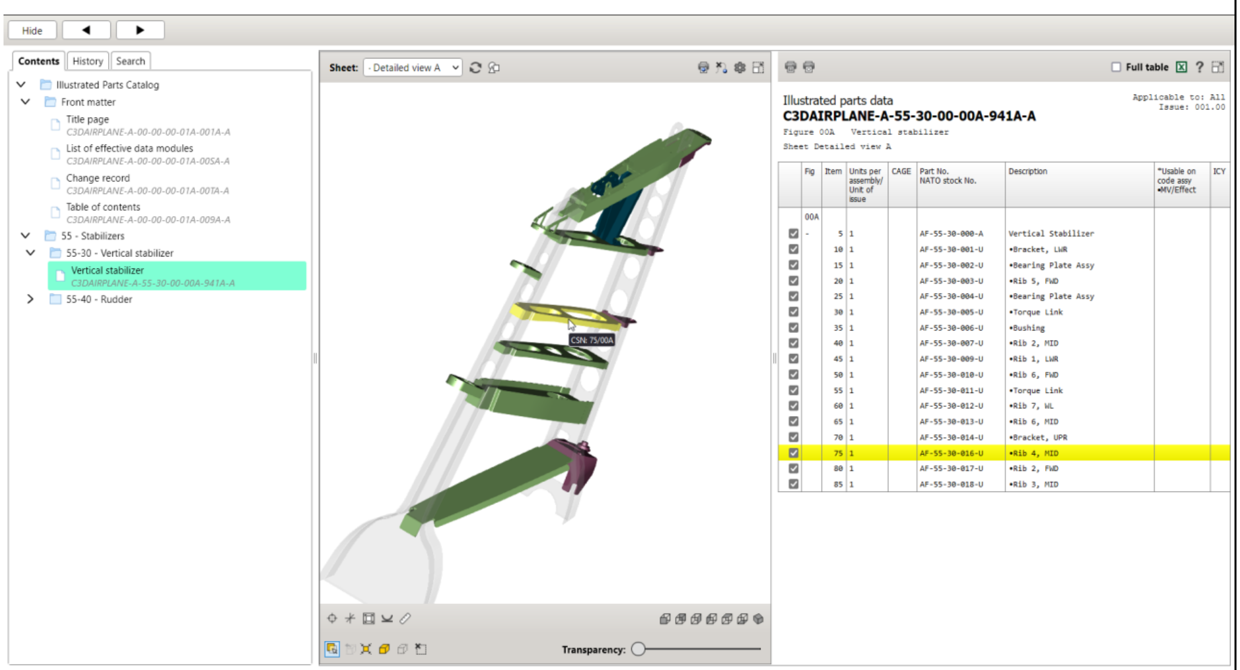
Notes:



Cortona3D Technical Documentation in the Digital Thread

The described process creates a partial digital twin of the product and follows a digital thread for technical documentation





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UCDth052: Cross-Discipline Engineering

USE CASE NUMBER: UCDth052	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐		
Use Case Owner: AD PAG (Cortona3D Notes)	**Associated Use Cases:** UCDth018		
Use Case Title: *Cross-Discipline Engineering*			
Description:	Accessibility and traceability of mechanical, electrical, electronics, and embedded software product content to cross-disciplinary engineering teams		
Goal:	Design coordination and integration of mechanical, electrical, electronics, and embedded software product content		
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐		
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Activity initiated on demand and as needed during coordination and system integration even		
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐ This is a function of the organizational size and whether coordination extends outside the enterprise to include suppliers		
Roles:	Design Engineer, System Engineer, Mechanical Engineer, Electrical Engineer, Software Developer, Security Engineering, and other engineering disciplines		
Preconditions:	Design completion based on customer/business requirements (A-Concept Stage)		
Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	Customer requirements are received	Customer requirements are documented
	2.	Product is designed per the customer's requirements	Product is designed
	3.	Electrical Engineer defines/designs the electrical system	Electrical specifications are available
	4.	Mechanical Engineer defines/designs the mechanical system	Mechanical specifications are available
	5.	Software Developer defines/designs the software system	Software specifications are available

↑ View Digital Twin List ↑ View Digital Thread List

	6.	Security Engineering defines/designs the security system	Security specifications are available
	7.	System Engineer defines/designs the product's systems	System specifications are available
	8.	The product structure is engineered	Structure specifications are available
Alternate Course(s) of Events:	The digital thread assists engineers and system architects to collaborate in a DevSecOps (Development, Security, Operations) approach to product engineering		
Data:			
Postconditions:	None		

Notes:

Notes and Image from Cortona3D:

Many technicians need both wiring and electrical data as part of the product documentation, but electrical and wiring data is typically separate from documentation based on engineering and design data.

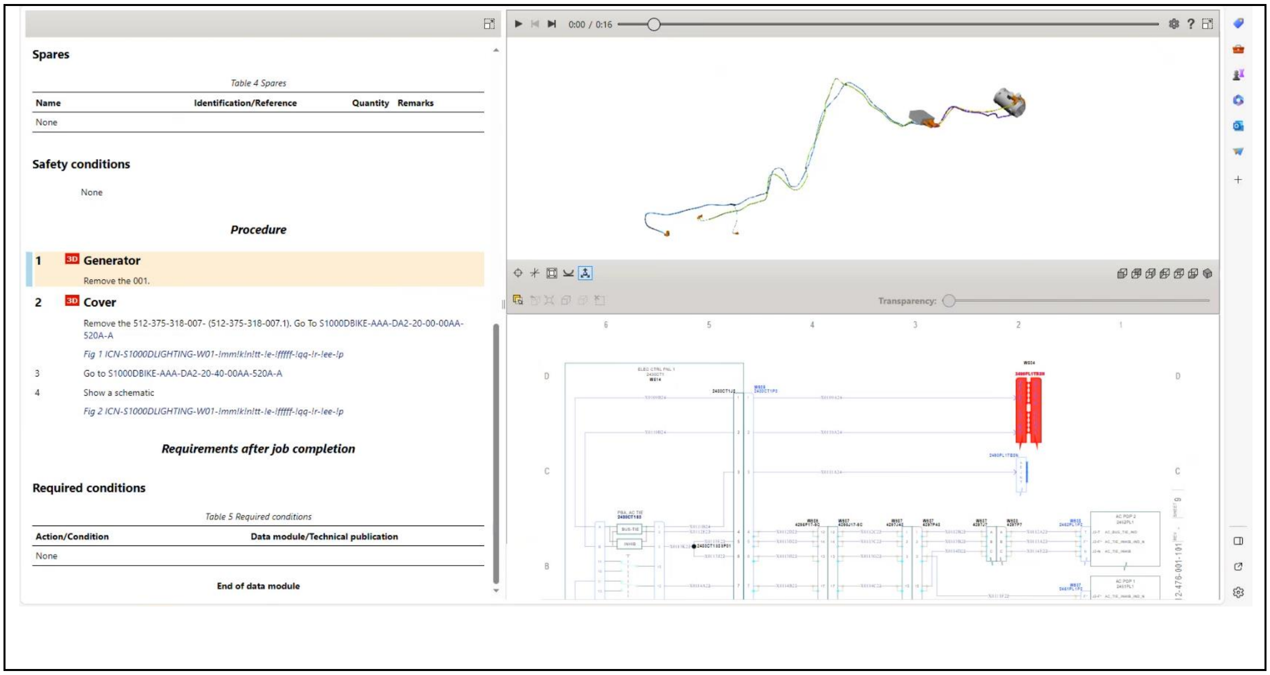
Outlook:

Cortona3D is working on integration between electrical and mechanical content to provide the technician with a merged view—a full overview of mechanical and electrical information at once, including links between the two layers. This is an unreleased functionality of which Cortona is in the process of gathering feedback.

The plan is to combine mechanical information accessed through Bill of Materials (BOM) and CAD data with electrical information received from another system (e.g., 2D wiring diagrams). The goal is to allow technicians to use one combined documentation source that shows the location of wires in both 3D and 2D wiring diagrams, improving disassembly and troubleshooting processes.

Description of the prototype screenshot shown below.

The procedure is described on the left; the interactive 3D with mechanical content is shown on the top right; and the corresponding wiring diagram is shown on the bottom right. When the cursor is hovered over/clicked on the 3D data, the corresponding part of the 2D wiring diagram is highlighted, making it easy to find the component and get additional information from the wiring diagram.



UCDth053: Long-Term Data Archival and Retrieval

USE CASE NUMBER: UCDth053	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐		
Use Case Owner: Cortona3D	**Associated Use Cases:** UCDth021		
Use Case Title: *Long-Term Data Archival and Retrieval*			
Description:	Long-term maintenance of data, including archival and retrieval of digital product and technical data Archiving is required until the product's End Of Life (EOL)		
Goal:	Long-term archival of the product data is enabled		
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒		
Roles:	Technical Author		
Preconditions:	Documentation created in RapidAuthor		
Special Requirements:	Publication to PDF (in addition to or instead of interactive 3D)		
Normal Course of Events:		**Action:**	**Result:**
	1.	Create RapidAuthor documentation	RapidAuthor project as the base for any type of publication
	2.	Publish to PDF	PDF for storage

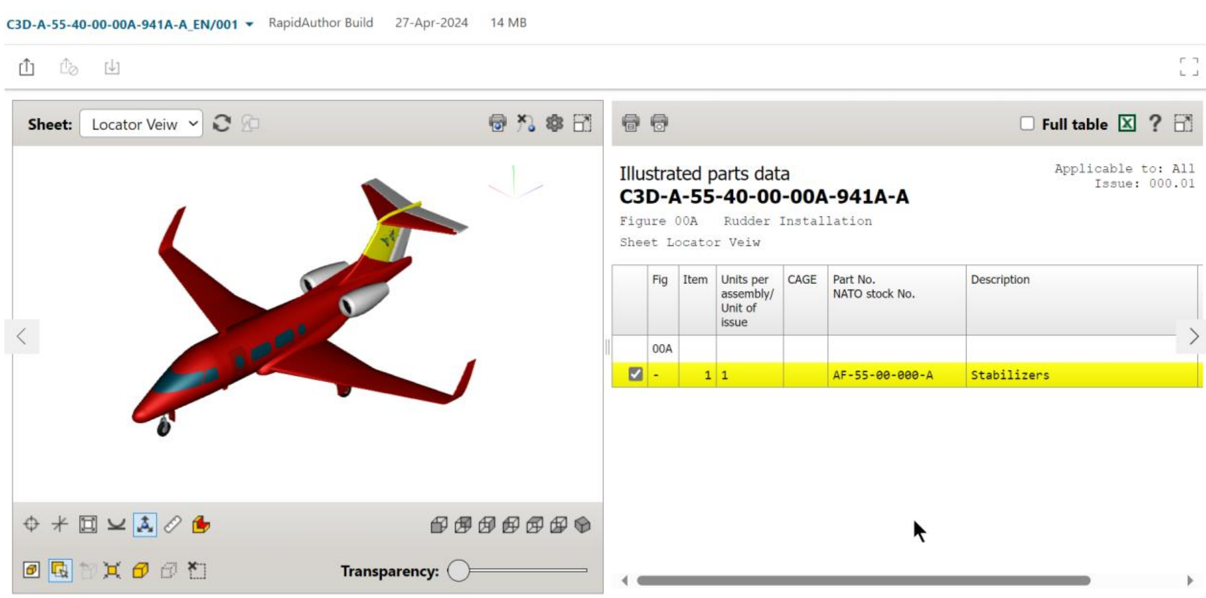
↑ View Digital Twin List ↑ View Digital Thread List

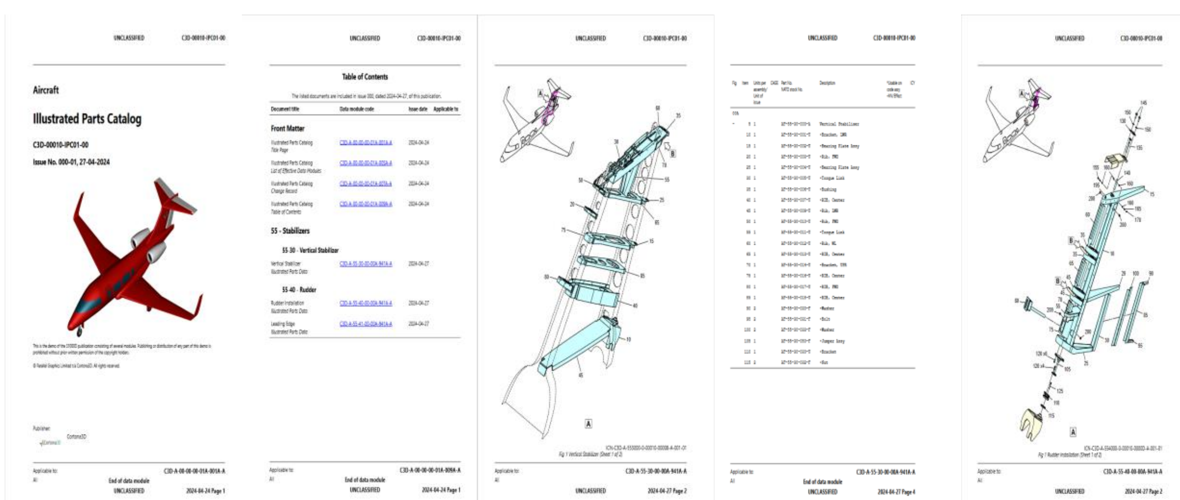
Alternate Course(s) of Events:	None
Data:	
Postconditions:	None

Notes:

Though this is considered a minor use case for Cortona3D, it is used by many customers. They may use RapidAuthor to create interactive 3D as their documentation for manufacturing, service, or training, but they additionally create PDFs automatically to store lightweight documentation in a traditional form to comply with regulations.

Interactive 3D documentation:





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UCDth054: Interactive Production and Maintenance

USE CASE NUMBER: UCDth054	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG (Cortona3D Notes)	**Associated Use Cases:** UCDth024
Use Case Title: *Interactive Production and Maintenance*	

Description:	Interact with products based on augmented reality using models and technical documentation		
Goal:	Interact with products based on augmented reality using models and technical documentation		
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☐ E-Support ☒ F-Retirement ☐		
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Event-based demand (i.e., Airplane On Ground (AOG)		
Impacted Population:	Less than 10 ☒ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐ Depending on the complexity of the event, the participating population ranges from less than 10 to over 100		
Roles:	Airline Maintenance Engineer, Airline Mechanic, Airline Operations, Original Equipment Manufacturer (OEM) Field Service Representative (FSR), OEM Service Support Engineer		
Preconditions:	Utilization of augmented reality is approved and defined with the customer/operator maintenance repair and overhaul procedures		
Special Requirements:	None		
Normal Course of Events: **There are two normal courses:** **1) Scheduled Maintenance** **2) Unscheduled Maintenance**		**Action:**	**Result:**
	1.	Customer/operator declares that the product (aircraft) is in an AOG status	Airline Maintenance Engineer, Airline Mechanic, and OEM FSR are dispatched to determine the cause of the AOG status
	2.	Root cause of AOG status is determined	Defined, documented, and augmented reality (Digital Twin) of AOG root cause is established
	3.	OEM is notified of the root cause determination	Augmented reality (Digital Twin) definition of the AOG is sent to the OEM Service Support Engineer

↑ View Digital Twin List ↑ View Digital Thread List

The scenario used in this use case is option 2 – unscheduled maintenance or AOG	4.	Owner/Operator/OEM collaborate on a corrective action plan using augmented reality to simulate both the repair and the operational capability	Simulation of corrective action repair and operational status is conducted
	5.	Corrective action documentation is prepared	Product corrective action plan documentation is authorized
	6.	Aircraft is repaired and operational readiness is validated	Product is returned to operational status
Alternate Course(s) of Events:	None		
Data:			
Postconditions:	None		

UCDth056: Generation, Configuration Management, and Impact Assessment of the Digital Thread

USE CASE NUMBER: UCDth056	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: eQ Technologic	**Associated Use Cases:**
Use Case Title: *Generation, Configuration Management, and Impact Assessment of the Digital Thread*	
Description:	eQube®-DaaS (Data as a Service) coupled with the eQube-DTA (Digital Thread Application) provides an integrated data fabric stitching data, applications, and devices through all the phases of a product development lifecycle while honoring data security, maintaining digital thread (DT) configuration management, and providing search and navigation in a single screen; this solution results in dramatic improvements in productivity, improved quality, unparalleled insights and access to data within and between the enterprise systems This use case features eQube-DTA, showing how a thread specification is created to filter the digital fabric for specific individuals/roles, how to use permissions and sharing capabilities, and how this tool makes possible impact assessment and conversations on the thread for an engineering review The eQube-DaaS platform and eQube-DTA are designed to be future-proof and system agnostic, and are built to enable adding, removing, and changing applications through the life of the product, allowing customers to incorporate new technologies as required

↑ View Digital Twin List ↑ View Digital Thread List

<table>
<tr><td>Goal:</td><td colspan="3">Provide the following to user(s) having different roles and needs:
1. Ability to maintain and navigate a configuration-controlled digital fabric
2. Update the digital fabric with a new object by searching an enterprise source using eQube-DTA and adding a node and relationships to a digital thread manually
3. An accelerated path to data discovery to view, manipulate, and analyze enterprise data with minimal training
4. A configuration-controlled thread that can be released for assessment and disposition of enterprise-wide changes to the product
5. A single, user-friendly, and intuitive interface to view and navigate threads, showing objects from multiple applications with different data models, architectures, and security
6. Ability to view, analyze, track, maintain, collaborate, and disposition changes within the digital thread in a simple-to-use, single-view, zero-client web app</td></tr>
<tr><td>Use Case Lifecycle Stage:</td><td colspan="3">A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒</td></tr>
<tr><td>Use Case Frequency:</td><td colspan="3">Daily ☒ Weekly ☒ Monthly ☒ Yearly ☒ Other ☒</td></tr>
<tr><td>Impacted Population:</td><td colspan="3">Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒</td></tr>
<tr><td>Roles:</td><td colspan="3">In order of the course of events:
• Program/Project Manager
• Requirement Engineer</td></tr>
<tr><td>Preconditions:</td><td colspan="3">Digital thread “System Design Review” and “Product Design Review” are baselined within use case UCDth049</td></tr>
<tr><td rowspan="2">Normal Course of Events:</td><td></td><td>Action:</td><td>Result:</td></tr>
<tr><td>1.</td><td>Welcome to the Digital Thread App:
Program Manager signs in, views the side menu bar, user area, and available application roles (including Owner and Analyst) and operations</td><td>Sign-in accomplished</td></tr>
</table>

	2.	**Digital Fabric Exploration:** Program Manager uses the Object Explorer to demonstrate how to navigate the whole fabric and how to view object metadata, including how to identify associated threads and how to perform an on-the-fly fetch from an Authoritative Source of Truth (ASoT) using the logged-in user's credentials	Program Manager is oriented to eQube-DTA, including general navigation, how to expand or collapse nodes, and how to view metadata
	3.	**Manual Stitch Creation:** Program Manager shows a requirement from DOORS NG that is not satisfied using the Thread Visualizer: • Use the right pane to add new node • Search for a Windchill document • Create a relationship to complete the thread	A manual stitch is created in the network graph
	4.	**Digital Thread Creation:** Requirement Engineer creates a new digital thread: • Create an Application Set • Create an Entity Set • Create a Digital Thread Specification • Create a Digital Thread	Requirement Engineer understands and explores Application Sets, Entity Sets, and Digital Thread Specifications and how they are combined to create a thread view of the digital fabric A new work-in-progress digital thread is created for the Requirement Engineer, comprised of a new Application Set, Entity Set, and Digital Thread Specification
	5.	**Digital Thread Visualization:** Requirement Engineer demonstrates the features of the digital thread's network graph view	Requirement Engineer navigates the digital thread's network graph view, filtering the graph, viewing ASoT details, and using a digital stitch URL Using the Analytics tab, the Requirement Engineer views pedigree (upstream) and impacted items (downstream) by using Related Objects Also using the Analytics tab, the Requirement Engineer views all digital threads that consume a given node by clicking Impact Analysis

	6.	**Digital Thread Collaboration:** Program/Project Manager views the existing baseline threads released during use case UCDth049	Program/Project Manager can identify changes to the digital thread that have occurred since the release of the thread; relations with red lines highlight the changes of the thread
	7.	Program/Project Manager adds notes to the digital thread	Notes are saved to the thread
	8.	Mechanical Engineer adds a reply to the digital thread	A trackable discussion occurs directly on the digital thread without having to enter other source applications
Data:			
Postconditions:	A digital thread, with objects that have been created as data flows through the eQube-DaaS digital backbone, has been explored, baselined, dispositioned, reviewed, and commented upon by different individuals		

Notes:

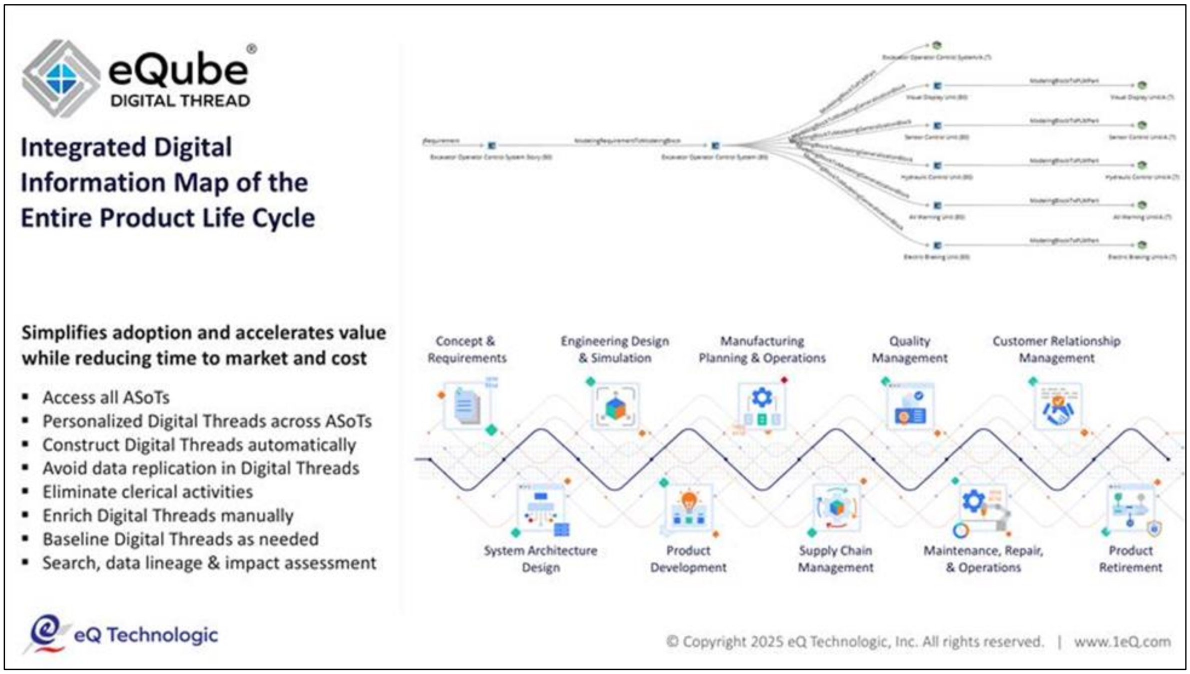
Definitions:

- eQube-DaaS
  "Data as a Service" platform which integrates data across enterprise applications via robust, configuration-controlled APIs and processes; includes the eQube applications, including eQube-BI (Business Intelligence) and eQube-MI (Migration and Integration)

- Digital Fabric
  The interconnected graph database which captures objects, relationships, and relationship types within and between ASoTs, created while data flows through the eQube-DaaS digital backbone

- Digital Thread
  Live report of the digital fabric with specific objects and relationships and a defined starting point; useful for a specific user persona and role; configuration-controlled, tailorable, configurable, and editable

- Stitch
  A single link between two ASoTs that shows the relationship between two entities and allows the user to navigate between them



eQube Dth: An Integrated Digital Information Map of the Entire Product Lifecycle

UCDth057: Design of Axial Compressor for Gas Turbine Engine

USE CASE NUMBER: UCDth057	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: Ansys	**Associated Use Cases:** UCDth005, UCDth007, UCDth009, UCDth011, UCDth015, UCDth017, UCDth018, UCDth021, UCDth023, UCDth025, UCDth028, UCDth031
Use Case Title: *Design of Axial Compressor for Gas Turbine Engine*	
Description:	This workflow focuses on the design of an axial compressor (continuously pressurizes gases) for a gas turbine engine through its various phases and stages of development from concept to the detailed design of a blade to the overall production of the compressor

↑ View Digital Twin List ↑ View Digital Thread List

Goal:	Demo use of Ansys Technologies to: • Enable the enterprise to interact with rich engineering deliverables to validate products before going into production and to improve design review efficiency • Assess cost and lead time impact of change and mitigate the compounding risks of change-on-change • Connect early engineering to field support, suppliers, and partners through bidirectional traceability and by enabling suppliers to engage key data via the digital thread • Ensure long-term maintenance of data, including archival and retrieval of the digital product and technical data • Certify designs without multiple physical prototypes; the digital thread facilitates the digital twin design simulations and certification, replacing the need to construct prototypes • Define and set up collaboration models, roles and responsibilities, and access rights • Co-design connectivity across the supply chain for both the product and production		
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☐ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐		
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒		
Roles:	Supplier, Design Engineer, Product Engineer, Materials Engineer, Simulation Engineer		
Preconditions:	Customer requirements are available, and business requirements have been defined and addressed by designing a product		
Normal Course of Events:		**Action:**	**Result:**
	1.	Define the objectives for the product design	Requirements are defined for product development
	2.	Establish the verification plan for the design	Design certification criteria is finalized
	3.	Review the requirements and identify the project resources	Task owners are defined for each step of the workflow
	4.	Design the concepts	Design concepts or options are identified for each stage
	5.	Create the CAD model	3D model for each design concept is created
	6.	Review the project status	Project management, automatic results extraction, traceability, and collaboration are assessed

↑ **View Digital Twin List** ↑ **View Digital Thread List**

	7.	Review and pass the design concepts	Design concepts are moved into the detailed design phase
	8.	Define the multi-tool simulation workflow	Advanced simulations, such as structural and airflow, are conducted
	9.	Identify the material properties for simulation	Collaboration with the supplier for material or test data is conducted
	10.	Approve the material model	Material properties were approved and released for use by the design and simulation users
	11.	Perform the simulation with the material properties	Results are collated and sent for review
	12.	Verify the results against the requirements	Results are approved and linked to the design in the PLM system

UCDth058: Model-Based Systems Engineering and Associated Topics

USE CASE NUMBER: UCDth058	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: Ansys	**Associated Use Cases:** UCDth009, UCDth010, UCDth011, UCDth015, UCDth017, UCDth018, UCDth028, UCDth029
Use Case Title: *Model-Based Systems Engineering and Associated Topics*	
Description:	• UCDth009 Closed-loop requirements linking and traceability through design, simulation, prototype and test • UCDth010 Modelling, simulation, and virtual analysis at all stages of the Requirement, Functional, Logical, and Physical (RFLP) • UCDth011 Digital thread ecosystem — Original Equipment Manufacturer (OEM) - Manufacturing - Supplier (OEM-MFG-Supplier) — for field change impact analysis; connection between early engineering to field support, suppliers, and partners; bidirectional traceability and enabling suppliers to engage key data via digital thread • UCDth015 Traceability of design rationale from early conceptual architecture through in-field sustainment; sustainment requirements are defined within the business requirements • UCDth017 Reuse of the pre-contract award work for post-contract award development ensured • UCDth018 Design coordination and integration of mechanical, electrical, electronics, and embedded software product content • UCDth028 Requirements specifications approved, change alerts received, change requests and releases managed • UCDth029 Collaboratively defined system architecture and interfaces, merging partners' work products

Goal:	Architectural modelling, simulation, and virtual analysis throughout all stages of system development (and specifically MBSE stages, such as Requirement, Functional, Logical, and Physical), while ensuring traceability, collaboration, and digital threading via configuration and information management		
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐		
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐		
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐		
Roles:	Requirements Analyst, Design Engineer, Systems Engineer, Data Analytics Engineer, Metrology Engineer, Data Analysis Engineer, Augmented Reality Engineer, Artificial Intelligence Expert, Requirements Specialist, Computer-Aided Management System (CAMS) Engineer, Digital Support Engineer, Quality Assurance (Q/A) Engineer, CAMS Specialist, Project Manager, Industrial Manufacturing System Engineer, Digital Engineering (on analysis; emerging capability)		
Preconditions:	Suitable information technology (IT) systems in place to support the use case		
Normal Course of Events:		**Action:**	**Result:**
	1.	Definition of business requirements are modelled, reviewed, and analyzed relative to modelling, simulation, and virtual analysis requirements (R)	Managed and configured business requirements are broken down (through configuration management) and are linked with the parameter set
	2.	Architecture model (FL) is defined and made traceable with the requirements	Architecture model configuration breakdown is managed and linked with the requirement and parameter set
	3.	Physical model (P) is defined and made traceable with the architecture model	Physical breakdown is managed in the configuration and linked with the requirement, architecture model, and parameter set
	4.	Variability model definition is applied to the RFLP model, and a description of alternatives is made	Features model is defined and constraints between the features are linked to the RFLP model
	5.	RFLP model undergoes global configuration management	Global configuration baseline of the RFLP model and variability model is defined
	6.	Trade-off analysis and a link with the analysis model are defined	Study is defined, stakeholders involved in the study are notified, and the RFLP and analysis models are linked through parameters

↑ **View Digital Twin List** ↑ **View Digital Thread List**

	7.	Analysis is launched	Based on the analysis type, the specific model (e.g., workflow, analysis, Multi-Disciplinary Analysis and Optimization (MDAO), co-simulation) is executed
	8.	Result is visualized	Cockpit dashboard is defined to visualize results and navigate between the RFLP viewpoint with a virtual assistant (i.e., usability for nonexpert end user)
	9.	Decision is made	Analysis and rationale for the decision are saved and managed in the configuration of the study
Alternate Course(s) of Events:	Step 5. Initialize the configuration tree at the beginning of the concept stage and store the RFLP and variability model at each step		
Data:	Requirements, Parameters, Function, Component, Product, Algorithms, Feature Model		
Postconditions:	Periodic quality assurance (Q/A) review to validate the alignment of digital twins and digital threads to physical object and systems		

Additional Use Cases

Presented in numerical order, the following digital thread use cases were prepared (in varying degrees of detail) but not demonstrated.

UCDth001: Model-Based Enterprise (MBE)

USE CASE NUMBER: UCDth001	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Model-Based Enterprise (MBE)*	
Description:	Enable the enterprise to interact with rich engineering deliverables, to validate products before going into production, and to improve design review efficiency
Goal:	Improve design review efficiency and product validation before production
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Continuous utilization – On demand
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒ Enterprise resource enabling multiple value streams

↑ View Digital Twin List ↑ View Digital Thread List

Roles:	All enterprise roles enable utilization of the enterprise digital threads; in addition to the PLM engineering roles, Finance, Human Resources, Legal, and other support organizations will interact with the MBE digital threads		
Preconditions:	A defined and supported digital thread operational environment that supports the modelled definition, access control, and authorized utilization		
Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	Customer requirement is received	A business requirement is defined
	2.	Business requirement is addressed by defining and designing the product/solution	Product/solution is defined and designed for Engineering
	3.	Product/solution is engineered	Engineered product/solution is prepared
	4.	Product/solution is manufactured/built	Product/solution is created
	5.	Product/solution is operated	Product/solution is used
	6.	Product/solution is supported	Product/solution is supported
	7.	Product/solution is disposed of	Resources are re-purposed
	8.	Cost models are forecasted	Cost Forecast models are available
	9.	Actuarial maintenance/repair models are developed	Actuarial maintenance and repair models are available
	10.	Sustainability compliance is confirmed	Sustainability compliance is complete
Alternate Course(s) of Events:	Recursive utilization of data and information, feedback loops		
Data:			
Postconditions:	None		

UCDth002: Lifecycle Bill of Materials (BOM) Management

USE CASE NUMBER: UCDth002	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Lifecycle Bill of Materials (BOM) Management*	
Description:	Complete highly visual product definition driven from Computer-Aided Design (CAD) and other descriptive artifacts for comprehensive configuration management across the product lifecycle
Goal:	Achieve comprehensive configuration management across the product lifecycle
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒
Roles:	(As-Designed) Designer; Design Checker; Design Approver; Digital Mockup (DMU) Integrator; Structure System Installation Manager; (As-Planned) Manufacturing Engineer; (As-Built) Manufacturer Supplier; (As-Delivered) Maintenance, Repair, and Overhaul (MRO)
Preconditions:	• Certification and validation of parts, check of the documentation and standards and relation to item of configuration (Configuration Item) • Archive ECN (Electronic Change Note) modification
Special Requirements:	None

Normal Course of Events:

	Action:	Result:
1.	Information linked to the BOM is generated	BOM is generated along the lifecycle with its identification
2.	BOM and its information are released	BOM is released and usable along the lifecycle
3.	Rights access to the BOM data and item data is managed	Rights management depends on export-control / data segregation, etc.
4.	Depending on the profile, read the BOM information	BOM is read
5.	Changes to the BOM are managed	Updated information is added
6.	Alternatives, item interchangeability, and mixability are provided	Alternatives / interchangeability / mixability are provided

	7.	Remarks are added	Remarks are added
	8.	All changes with authorization (authors identity by design authority) at BOM and items levels are logged	BOM historical changes are logged
	9.	BOM information is archived	BOM is archived
	10.	Consistency and continuity between all views of the BOM (along the lifecycle) is ensured	Gaps are avoided due to ensured BOM data continuity
	11.	Depending on the authoring context, multi-view capability is provided	Multiview capability is provided if applicable
	12.	Versions of the BOM are managed	BOM is managed in the versions
Alternate Course(s) of Events:	None		
Data:	Configuration Item (CI) / Standard Part / Elementary Part / Assembly Validation of Characteristics (Standards and Compliance), Validation of Workflow (As-Planned)		
Postconditions:	None		
Notes:	None		

UCDth003: Service and Customer Documentation

USE CASE NUMBER: UCDth003	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Service and Customer Documentation*	
Description:	Develop technical documentation based directly on digital thread content
Goal:	Develop technical documentation based directly on digital thread content
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☒ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☒ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒

↑ [View Digital Twin List] ↑ [View Digital Thread List]

<table>
<tr><td>Roles:</td><td colspan="3">Technical Publications (Tech Pub); Customer Service Center (CSC) Field Service Engineer (FSE); Product Service Engineer (PSE); Maintenance, Repair, and Overhaul (MRO); Maintenance Shops</td></tr>
<tr><td>Preconditions:</td><td colspan="3">All the technical documentation must be standards based (e.g., S1000D or a similar standard, such as Air Transport Association (ATA))
Possible digital thread (part number) link between the changes and the maintenance tasks must exist.</td></tr>
<tr><td>Special Requirements:</td><td colspan="3">None</td></tr>
<tr><td rowspan="6">Normal Course of Events:</td><td></td><td>Action:</td><td>Result:</td></tr>
<tr><td>1.</td><td>New Change In Definition (CID) is validated for the product</td><td>Maintenance tasks affected by this CID are identified and the owners—Product Systems Engineering (PSE)—of these tasks are notified and included in the validation workflow</td></tr>
<tr><td>2.</td><td>New 3D and 2D drawings eventually associated with this CID are released in the PLM</td><td>A draft of the maintenance tasks with updated 3D/2D drawings from the PLM is available to the tasks' owners and Technical Publications for review</td></tr>
<tr><td>3.</td><td>CID is validated</td><td>Final content of the CID is available to finalize the update of maintenance tasks</td></tr>
<tr><td>4.</td><td>Maintenance tasks are updated on the customer portal</td><td>Maintenance tasks content is synchronized according to the technical documentation standards</td></tr>
<tr><td>5.</td><td>Customer interacts with the customer portal</td><td>Customer sees the updated maintenance tasks</td></tr>
<tr><td>Alternate Course(s) of Events:</td><td colspan="3">The 3D elements are specific to aftersales and are not referenced in the PLM. There is a need to split/create new maintenance tasks (i.e., new, revised, and unplanned, such as Aircraft On Ground (AOG)). Two distinct tasks are using the same content.</td></tr>
<tr><td>Data:</td><td colspan="3">Word documents (CID), Objects in configuration PLM, XML/CATParts/SVG in Technical Publications portal</td></tr>
<tr><td>Postconditions:</td><td colspan="3">Format exportable to big customers (e.g., Lufthansa), also known as "raw data" format for import into the customer technical publications system.</td></tr>
<tr><td>Notes:</td><td colspan="3">S1000D Specification: https://s1000d.org/</td></tr>
</table>

UCDth005: Change Impact Assessment

USE CASE NUMBER: UCDth005	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐	
Use Case Owner: AD PAG	**Associated Use Cases:**	
Use Case Title: *Change Impact Assessment*		
Description:	Traceability for synchronization of updates between the digital asset (digital twin) and physical asset(s) to assess cost and lead time impact of change and to mitigate compounding risks of change-on-change	
Goal:	Facilitate assessment of cost and lead time impact of change, and mitigate compounding risks of change-on-change	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☒ F-Retirement ☐	
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Synchronization occurs daily, as needed, and when synchronization is required due to a product change Synchronization can be initiated by the digital twin or by the physical object	
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐ Population size is a function of the change type and size of the organization/ enterprise and the number of organizations/companies involved in the change	
Roles:	Project Manager, Cost Analyst, Risk Analyst, Digital Twin Analyst/Engineer	
Preconditions:	Change decision has been approved and reviewed by the respective engineering, quality, and other decision-making authorities	
Normal Course of Events:	**Action:**	**Result:**
	1. Authorized Engineering Change Request (ECR) is received and reviewed	The following are initiated: • Proposed project schedule revision, cost analysis, and risk analysis • Digital twin synchronization statement of work
	2. Digital twin synchronization statement of work is reviewed, and the digital twin revision and re-synchronization plans are prepared	Digital twin revision and re-synchronization plans and test plans are reviewed and implemented
Alternate Course(s) of Events:	None	
Data:		

↑ View Digital Twin List ↑ View Digital Thread List

Postconditions:	None
Notes:	None
Data:	

UCDth007: Supply Chain Collaboration

USE CASE NUMBER: UCDth007	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Supply Chain Collaboration*	
Description:	Co-design connectivity across the supply chain for both the product and production
Goal:	Improve connectivity for effective co-design across the supply chain
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒
Roles:	Designer, System Engineering, Manufacturing Engineering, Procurement, Quality Manager, Logistics Manager, Customer Service
Preconditions:	• A legal framework with Intellectual Property (IP) protection and export-control constraints • Antitrust rules (data contract concept) should be in place for sharing visibility with the external supply chain
Special Requirements:	None

Normal Course of Events:

	Action:	**Result:**
1.	Design with technical specifications is submitted to suppliers	Business requirement is defined
2.	A contract is signed	Product/Solution is defined
3.	Requirements are validated with the partners	Product/Solution is engineered
4.	PLM solution is integrated	Product/Solution is available

↑ **View Digital Twin List** ↑ **View Digital Thread List**

	5.	Product/Solution is qualified	Product/Solution is put to use
	6.	Part is manufactured	Product/Solution is supported
	7.	Part is received	Resources are re-purposed
	8.	Part is integrated/the Bill of Materials (BOM) is updated	Cost forecast models are prepared
	9.	Part is supported	Actuarial maintenance and repair models are prepared
Alternate Course(s) of Events:	Recursive utilization of data and information, feedback loops		
Data:	Collaborative lifecycle BOM / key characteristics / parts traceability / part environments		
Postconditions:	None		
Notes:	None		

UCDth008: Support Product in Service

USE CASE NUMBER: UCDth008	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐		
Use Case Owner: AD PAG	**Associated Use Cases:**		
Use Case Title: *Support Product in Service*			
Description:	Capture, as closely as possible, the state of the product (i.e., configuration, maintenance and repair, operations) to provide adaptive support (malfunction solving, repair solutions, etc.)		
Goal:	Facilitate adaptive support (malfunction solving, repair solutions, etc.)		
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☒ E-Support ☒ F-Retirement ☒		
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐		
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐		
Roles:	Support Engineer		
Preconditions:	Issue (or problem) spotted on an in-service product by the operator		
Normal Course of Events:		**Action:**	**Result:**
	1.	Support Engineer receives information about the issue	Support Engineer reviews the information

↑ View Digital Twin List ↑ View Digital Thread List

	2.	Support Engineer locates the issue with the product	Location shown in a 3D representation of the product
	3.	Support Engineer requests information about the issue location's surroundings	3D model shows nearby parts with already-known problems (on this or other products) 3D model shows reliability data about the nearby parts
	4.	Support Engineer requests information about the maintenance and repair performed on or around issue location	3D model shows repair operations, as well as scheduled and unscheduled maintenance operations, performed near the issue location
	5.	Support Engineer requests operational information about the product	Digital thread shows operational information about the product (e.g., utilization data, weather conditions, weight, etc.)
	6.	Support Engineer uses the collected data to establish a diagnosis and propose to the operator a course of action for resolution	Course of action is proposed
Alternate Course(s) of Events:	None		
Data:			
Postconditions:	None		
Notes:	None		

UCDth009: Design Optimization and Validation

USE CASE NUMBER: UCDth009	**Use Case Type: Digital Thread** ☒	**Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**	
Use Case Title: *Design Optimization and Validation*		
Description:	Closed-loop requirements linking and traceability through design, simulation, prototype, and test	
Goal:	Facilitate optimization of design and validation through closed-loop requirements linking and traceability	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐	

↑ View Digital Twin List ↑ View Digital Thread List

Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Event-driven frequency		
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐ Primarily utilized within the Design and Engineering organizations; maybe utilized by Manufacturing, Operations and Customer Engineering		
Roles:	Designer, Systems Engineer, Simulation Engineer, Test Engineer		
Preconditions:	Customer product requirements are needed to perform this step/function		
Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	Customer requirements are received	Customer requirements are documented
	2.	Product is designed per the customer's requirements	Product is designed
	3.	Product prototype is developed/constructed	Product prototype is created
	4.	Product simulation is defined and performed	Product simulation results are noted
	5.	Product testing is defined and performed	Product test results are noted
	6.	Simulation and test results are provided to the Product Designer	Simulation and test results are made available via the digital thread
Alternate Course(s) of Events:	Digital thread accessibility to product design, test, simulation, and customer requirements data		
Data:			
Postconditions:	Design conforming to requirements. Simulation and test validate product conformity to customer requirements.		

UCDth010: Model-Based Systems Engineering (MBSE)

USE CASE NUMBER: UCDth010	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Model-Based Systems Engineering (MBSE)*	

↑ View Digital Twin List ↑ View Digital Thread List

Description:	Modelling, simulation, and virtual analysis at all stages of the Requirement, Functional, Logical, and Physical (RFLP)
Goal:	Traceability across artifacts from modelling, simulation, and virtual analysis at all RFLP stages
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒
Roles:	Requirements Analyst, Design Engineer, Systems Engineer, Data Analytics Engineer, Metrology Engineer, Data Analysis Engineer, Augmented Reality Engineer, Artificial Intelligence Expert, Requirements Specialist, Computer-Aided Management System (CAMS) Engineer, Digital Support Engineer, Quality Assurance (Q/A) Engineer, CAMS Specialist, Project Manager, Industrial Manufacturing System Engineer, Digital Engineering (on analysis; emerging capability)
Preconditions:	None
Special Requirements:	• Access right management, Intellectual Property protection, Data classification (e.g., export-control, International Traffic in Arms Regulations (ITAR)), extended enterprise (connection to other PLM), scalable solution with response time acceptable for the end user, long-term archive independent of the tools (and its version) • Extensive validation and confirmation of requirements may need to occur with each system design and construction review • Additional SMEs and technology that are not currently define may be required

Normal Course of Events:

	Action:	Result:
1.	Definition of business requirements are modelled, reviewed, and analyzed relative to modelling, simulation, and virtual analysis requirements (R)	Managed and configured business requirements are broken down (through configuration management) and are linked with the parameter set
2.	Architecture model (FL) is defined and made traceable with the requirements	Architecture model configuration breakdown is managed and linked with the requirement and parameter set
3.	Physical model (P) is defined and made traceable with the architecture model	Physical breakdown is managed in the configuration and linked with the requirement, architecture model, and parameter set

↑ View Digital Twin List ↑ View Digital Thread List

	4.	Variability model definition is applied to the RFLP model, and a description of alternatives is made	Features model is defined and constraints between the features are linked to the RFLP model
	5.	RFLP model undergoes global configuration management	Global configuration baseline of the RFLP model and variability model is defined
	6.	Trade-off analysis and a link with the analysis model are defined	Study is defined, stakeholders involved in the study are notified, and the RFLP and analysis models are linked through parameters
	7.	Analysis is launched	Based on the analysis type, the specific model (e.g., workflow, analysis, Multi-Disciplinary Analysis and Optimization (MDAO), co-simulation) is executed
	8.	Result is visualized	Cockpit dashboard is defined to visualize results and navigate between the RFLP viewpoint with a virtual assistant (i.e., usability for nonexpert end user)
	9.	Decision is made	Analysis and rationale for the decision are saved and managed in the configuration of the study
Alternate Course(s) of Events:	Step 5. Initialize the configuration tree at the beginning of the concept stage and store the RFLP and variability model at each step		
Data:	Requirements, Parameters, Function, Component, Product, Algorithms, Feature Model		
Postconditions:	Periodic quality assurance (Q/A) review to validate alignment of digital twins and digital threads to physical object and systems		

UCDth011: Bidirectional Traceability

USE CASE NUMBER: UCDth011	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Bidirectional Traceability*	
Description:	Digital thread ecosystem—Original Equipment Manufacturer - Manufacturing - Supplier (OEM-MFG-Supplier)—for field change impact analysis Connection between early engineering to field support, suppliers, and partners
Goal:	Bidirectional traceability and suppliers able to engage key data via the digital thread
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ On-demand
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒
Roles:	Design Engineer, Manufacturing Engineer, Quality Assurance Engineer, Maintenance Planner, Maintenance Engineer, Airframe/Powerplant (A/P) Mechanic, Field Service, Supplier, Regulatory Representative
Preconditions:	None
Special Requirements:	None

Normal Course of Events:		**Action:**	**Result:**
	1	Customer requirement is received	Business requirement is defined
	2.	Digital thread product/solution is designed	Digital thread product/solution definition is prepared
	3.	Digital thread product/solution is engineered	Engineered digital thread product/solution is available
	4.	Digital thread product/solution is manufactured/built	Digital thread product/solution is ready for simulation
	5.	Product/Solution using the digital thread is simulated	Simulated digital twin product/solution

Alternate Course(s) of Events:	None
Data:	Design, Engineering, Manufacturing, Process, Q/A, Delivery, Operation, Maintenance, Modification, Test, Supplier component
Postconditions:	None

UCDth012: Final Inspection Before Customer Delivery

USE CASE NUMBER: UCDth012	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Final Inspection Before Customer Delivery*	
Description:	Final inspection of Leading-Edge Aviation Propulsion (LEAP) engines based on the configuration As-Planned–As-Built (SAE, Society of Automotive Engineers)
Goal:	Ensure that the Engine As-Built BOM is the same as the As-Designed BOM

↑ View Digital Twin List ↑ View Digital Thread List

<table>
<tr><td>Use Case Lifecycle Stage:</td><td colspan="3">A-Concept ☐ B-Development ☒ C-Production ☒ D-Utilization ☐
E-Support ☐ F-Retirement ☐</td></tr>
<tr><td>Use Case Frequency:</td><td colspan="3">Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐</td></tr>
<tr><td>Impacted Population:</td><td colspan="3">Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐
More than 1000 ☐</td></tr>
<tr><td>Roles:</td><td colspan="3">Mount Inspectors, Mounters</td></tr>
<tr><td>Preconditions:</td><td colspan="3">Engine is mounted; digital twin exists and represents the physical engine</td></tr>
<tr><td>Special Requirements:</td><td colspan="3">None</td></tr>
<tr><td rowspan="4">Normal Course of Events:</td><td></td><td>Action:</td><td>Result:</td></tr>
<tr><td>1.</td><td>LEAP engine is presented for BOM inspection</td><td>As-Built BOM is compared to the As-Designed BOM using manual/semi-manual processes
A great deal of human error is possible during this laborious task</td></tr>
<tr><td>2.</td><td>LEAP engine is presented for visual inspection</td><td>An operator, Cobot (cooperative robot), or cameras check if the engine is identical to the theoretical 3D representation of the BOM As-Designed
A great deal of human error is possible during this laborious task</td></tr>
<tr><td>3.</td><td>LEAP engine is weighed</td><td>Engine weight is compared to the theoretical one</td></tr>
<tr><td>Alternate Course(s) of Events:</td><td colspan="3">• Compare the physical engine to its digital twin by way of a robot with cameras that show discrepancies
• Scan the engine through QR codes (quick-response codes) or similar technologies to compare it to its digital twin</td></tr>
<tr><td>Data:</td><td colspan="3"></td></tr>
<tr><td>Postconditions:</td><td colspan="3">None</td></tr>
<tr><td>Notes:</td><td colspan="3">The robot solution noted above is partially implemented at Safran. Refer to this article for a glimpse of the process: https://www.lesechos.fr/weekend/business-story/comment-safran-resiste-au-mal-de-lair-1272302</td></tr>
</table>

UCDth013: Manufacturing Execution

USE CASE NUMBER: UCDth013	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Manufacturing Execution*	
Description:	Deliver work instructions based directly on digital thread from the Manufacturing Bill of Material (MBOM) down to the shop floor
Goal:	Work instructions based directly on digital thread from the Manufacturing Bill of Material (MBOM) accessible to the shop floor
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Frequency is based on scheduled (daily) and event-based changes to work instructions
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	Manufacturing Engineer, Configuration Manager, Factory Technician, Assembly Workers, Quality Assurance, Training – work instructions, Tooling Engineer, Environmental Engineer, Safety Engineer
Preconditions:	Scheduled for update, validation of requested change, validation of environment
Special Requirements:	None

Normal Course of Events:

	Action:	**Result:**
1.	MBOM – Change is needed	New or revised shop floor instruction(s) is created
2.	Manufacturing Engineer reviews the change	Floor instruction(s) is approved
3.	Sequence of reviews and approvals (see list of roles) are conducted	Work instruction(s) is reviewed and approved for implementation
4.	Implementation of revised work instruction(s) is scheduled	Implementation schedule is approved
5.	Implementation occurs based on the schedule	Change(s) is implemented
6.	Follow-up, including validation of the change(s), is conducted	Implementation is confirmed

↑ View Digital Twin List ↑ View Digital Thread List

Alternate Course(s) of Events:	Based on a planned change or an on-demand change as the workflow varies
Data:	MBOM, work instruction(s), etc.
Postconditions:	None
Notes:	None

UCDth014: Condition-Based and Predictive Maintenance with Feedback Loops

USE CASE NUMBER: UCDth014	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: Ad PAG	**Associated Use Cases:**
Use Case Title: *Condition-Based and Predictive Maintenance with Feedback Loops*	
Description:	Traceable linkages that aggregate sensor data, artificial intelligence models, and physics-based reliability models to aid in proactive maintenance and sustainment work **Clarification:** The focus is on the feedback loop to improve the design/definition/performance of the Condition-Based Maintenance (CBM)/Predictive models **Assumption:** Reinjection in the Development Stage (B) closes the loop
Goal:	Feedback loop from field operation to Development to improve the design/definition/performance of the Condition-Based Maintenance (CBM)/Predictive models
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒
Use Case Frequency:	Daily ☐ Weekly ☒ Monthly ☒ Yearly ☒ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒
Roles:	Primarily Designers and System/Structure Engineers
Preconditions:	Condition-Based and Predictive Maintenance (PdM) is deployed; Performance criteria for the CBM and PdM are defined
Special Requirements:	None

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Normal Course of Events:		**Action:**	**Result:**
	1.	Automatically analyze the collected raw data, its associated prediction, and its outcome	Need for model improvement is triggered
	2.	Improve the model, based on in-service usage	New model is generated
	3.	Validate and deploy the model in production (progressively or not)	New model is deployed
	4.	Restart at Step 1	Loop
Alternate Course(s) of Events:	None		
Data:	Aircraft usage data, Prediction data, Maintenance data (on aircraft and workshop reports)		
Postconditions:	None		
Notes:	None		

UCDth015: Design Rationale Traceability for Sustainment Decisions

USE CASE NUMBER: UCDth015	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Design Rationale Traceability for Sustainment Decisions*	
Description:	Traceability of design rationale from early conceptual architecture through in-field sustainment Sustainment requirements are defined within the business requirements
Goal:	Traceability of design rationale from early conceptual architecture through in-field sustainment
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Sustainment decisions occur primarily at product requirements definition and are revised as needed during the Concept and Development lifecycle stages

Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐ Population size is a function of the organization, complexity of the product, number of organizations and whether any regulatory compliance is required		
Roles:	Designer, Systems Engineer, Manufacturing Engineer, Structures Engineer, Electrical Engineer, Mechanical Engineer, Facilities Engineer, Sustainability Engineer, Sustainability Compliance, and Customer Engineer		
Preconditions:	None		
Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	Customer requirement is received	Sustainability requirement is defined
	2.	Product/Solution is designed	Product sustainability solution is defined
	3.	Product/Solution is engineered	Engineered product sustainability solution exists
	4.	Product/Solution is manufactured/built	Product manufacture/build sustainability solution is created
	5.	Product/Solution is operated	Product sustainability solution is utilized
	6.	Product/Solution is supported	Product support sustainability solution is utilized
	7.	Product/Solution is disposed of	Product/Solution is repurposed/reused based on the sustainability resource plan
	8.	Sustainability models are developed	Sustainability models are available
	9.	Actuarial Sustainment models are developed	Actuarial Sustainment models exist for compliance confirmation
	10.	Sustainability compliance is confirmed	Sustainability compliance is achieved
Alternate Course(s) of Events:	None		
Data:			
Postconditions:	None		
Notes:	None		

UCDth016: Model-Based Repair Publication

USE CASE NUMBER: UCDth016	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐	
Use Case Owner: AD PAG	**Associated Use Cases:**	
Use Case Title: *Model-Based Repair Publication*		
Description:	Model-based repairs alignment with the technical publication Connect the build and the repair instructions back to the Model-Based Design (MBD)	
Goal:	Build and repair instructions connected back to the Model-Based Design (MBD)	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☒ F-Retirement ☒	
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ On demand or based on repair event	
Impacted Population:	Less than 10 ☒ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☐	
Roles:	Design Engineer, System Engineer, Airline Maintenance Engineer, Sustainability Engineer	
Preconditions:	None	
Special Requirements:	None	

Normal Course of Events:

	Action:	Result:
1.	Airline mechanic notes the maintenance action from the aircraft log	Maintenance/repair event is initiated
2.	Airline Maintenance Engineer consults the model-based flight line support model for the specified maintenance event	Original Equipment Manufacturer (OEM) Design Engineer is notified of the design issue
3.	OEM Design Engineer references the MBD in its configured context to determine if the maintenance/repair event is within the design context	Maintenance Engineer and Airline Maintenance Engineer confer with the OEM Design Engineer regarding the Model-Based Maintenance for repair and any needed design revisions
4.	Repair plan prepared and authorized by OEM	Airline receives authorized repair plan

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	5.	Airline Maintenance Engineering prepares engineering repair plan for maintenance repair work package task cards	Approved maintenance repair work package
Alternate Course(s) of Events:	None		
Data:	MBD, model-based flight line support, model-based maintenance and operations		
Postconditions:	None		

UCDth017: Conceptual Design Traceability to Detailed Design

USE CASE NUMBER: UCDth017	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐		
Use Case Owner: AD PAG	**Associated Use Cases:**		
Use Case Title: *Conceptual Design Traceability to Detailed Design*			
Description:	Accessibility and traceability pre-contract award artifacts to post-contract award development team		
Goal:	Ensure reuse of the pre-contract award work for post-contract award development		
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐		
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐		
Impacted Population:	Less than 10 ☒ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☐		
Roles:	Systems Engineer, Design Engineer, Analysis Engineer, Compliance Verification Engineer, Engineering Quality, Manufacturing Engineer, Manufacturing Quality, Chief Engineer, Program Manager		
Preconditions:	Available business requirements (from customer)		
Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	Review of the business requirements (Systems Engineering)	Requirements and high-level architecture are defined
	2.	Design Engineer reviews the requirements and creates the preliminary design	System requirements and preliminary design are defined

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	3.	Engineering preliminary design is reviewed by design/manufacturing team	Preliminary engineering design is approved and compiled by the design team
	4.	Contract proposal is prepared by the Program Manager/Commercial	Proposal is submitted to the customer
	5.	Detailed design is prepared by the design team	Detailed design for chosen concept(s) is created by the design team
Alternate Course(s) of Events:	In the case of Make-to-Print business, the customer provides the detailed design		
Data:			
Postconditions:	None		
Notes:	None		

UCDth018: Cross-Discipline Engineering

USE CASE NUMBER: UCDth018	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Cross-Discipline Engineering*	
Description:	Accessibility and traceability of mechanical, electrical, electronics, and embedded software product content to cross-disciplinary engineering teams
Goal:	Design coordination and integration of mechanical, electrical, electronics, and embedded software product content
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Activity initiated on demand and as needed during coordination and system integration even
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐ This is a function of the organizational size and whether coordination extends outside the enterprise to include suppliers
Roles:	Design Engineer, System Engineer, Mechanical Engineer, Electrical Engineer, Software Developer, Security Engineering, and other engineering disciplines
Preconditions:	Design completion based on customer/business requirements (Concept Stage (A))

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Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	Customer requirements are received	Customer requirements are documented
	2.	Product is designed per the customer's requirements	Product is designed
	3.	Electrical Engineer defines/designs the electrical system	Electrical specifications are available
	4.	Mechanical Engineer defines/designs the mechanical system	Mechanical specifications are available
	5.	Software Developer defines/designs the software system	Software specifications are available
	6.	Security Engineering defines/designs the security system	Security specifications are available
	7.	System Engineer defines/designs the product's systems	System specifications are available
	8.	The product structure is engineered	Structure specifications are available
Alternate Course(s) of Events:	The digital thread assists engineers and system architects to collaborate in a DevSecOps (Development, Security, Operations) approach to product engineering		
Data:			
Postconditions:	None		

UCDth019: Manufacturing Engineering

USE CASE NUMBER: UCDth019	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Manufacturing Engineering*	
Description:	Derive plant-specific Manufacturing Bill of Materials (MBOMs) from Engineering Bill of Materials (EBOMs) Derive process plans and work instructions based on the upstream EBOM

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<table>
<tr><td>Goal:</td><td colspan="3">Plant-specific Manufacturing Bill of Materials (MBOMs) from Engineering Bill of Materials (EBOMs)

Process plans and work instructions based on the upstream EBOM</td></tr>
<tr><td>Use Case Lifecycle Stage:</td><td colspan="3">A-Concept ☐ B-Development ☒ C-Production ☒ D-Utilization ☐
E-Support ☐ F-Retirement ☐</td></tr>
<tr><td>Use Case Frequency:</td><td colspan="3">Daily ☒ Weekly ☒ Monthly ☐ Yearly ☐ Other ☐</td></tr>
<tr><td>Impacted Population:</td><td colspan="3">Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☒
More than 1000 ☐</td></tr>
<tr><td>Roles:</td><td colspan="3">Design Chief Engineer, Manufacturing Configuration (MBOM), Manufacturing Engineer (Bill of Process (BOP)), Manufacturing Preparer (Work Instruction (WI)), Manufacturing Preparer (Computer Numerical Control (CNC)), Manufacturing Quality Engineer, Process Engineer, Process Time Optimizer</td></tr>
<tr><td rowspan="8">Normal Course of Events:</td><td></td><td>Action:</td><td>Result:</td></tr>
<tr><td>1.</td><td>Manufacturing Engineer (ME) receives the released design Technical Data Package (TDP)/dossier, including EBOM</td><td>ME approves the design TDP (including EBOM) and starts the manufacturing setup (detailed process initialization)</td></tr>
<tr><td>2.</td><td>Configured detailed process is initiated from the macro-build process</td><td>Detailed process skeleton is part of the configuration</td></tr>
<tr><td>3.</td><td>Control Plan is created (Quality Engineer responsibility)</td><td>Released Control Plan, based on Process Failure Mode and Effects Analysis (PFMEA), is available</td></tr>
<tr><td>4.</td><td>Manufacturing setup is created (authoring of detailed process)</td><td>Released operations with allocated BOM and resources (skills, qualifications of people, tools, etc.) and work instructions are defined</td></tr>
<tr><td>5.</td><td>Inspection preparation/plan is created</td><td>Inspection operation part of the detailed process (i.e., released inspection preparation/plan per operation) is in place</td></tr>
<tr><td>6.</td><td>First Article Inspection (FAI) in the Production Stage (C) is performed</td><td>FAIR (FAI Report) is created</td></tr>
<tr><td>7.</td><td>Feedback loop, based on FAIR, is initiated</td><td>Processes in the configuration are corrected as needed</td></tr>
<tr><td>Alternate Course(s) of Events:</td><td colspan="3">None</td></tr>
</table>

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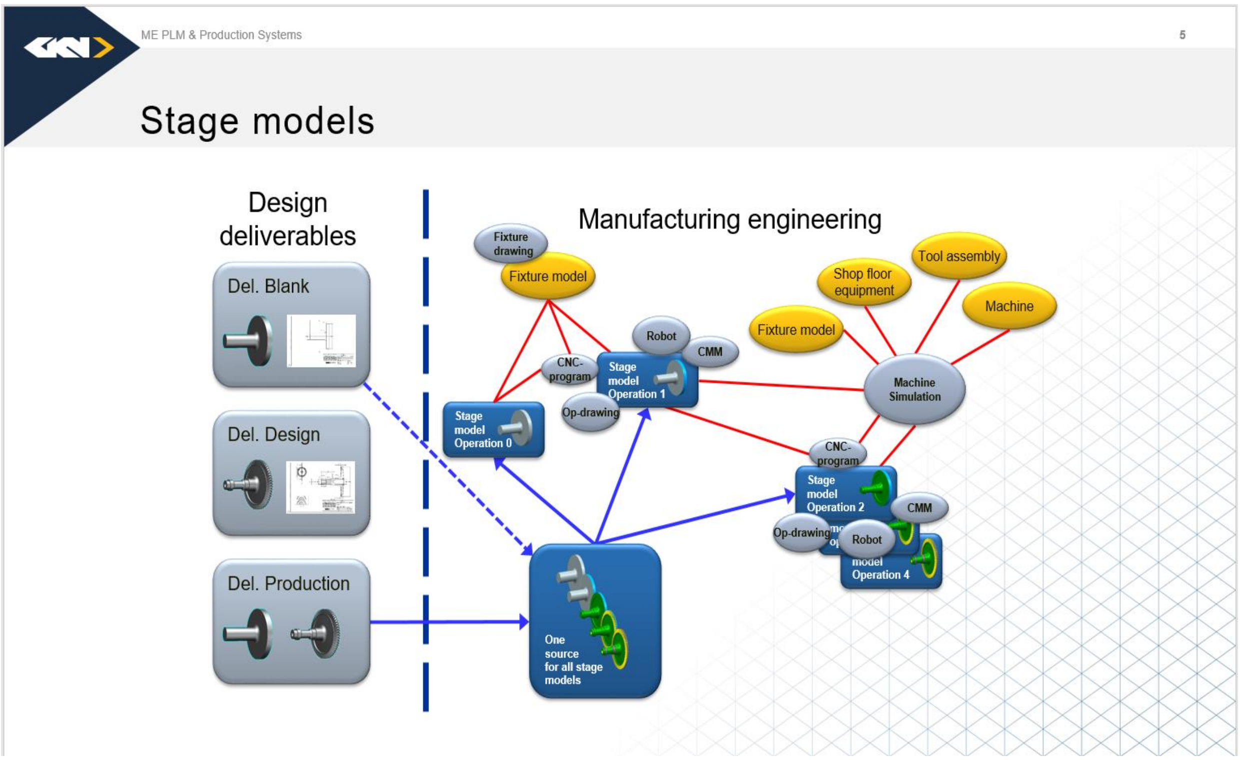
Data:	Per order of importance: 1 – Configured EBOM 2 – Configured Process 3 – MBOM 4 – Resources 5 – Work Instructions
Postconditions:	None
Notes:	Process-centric approach before the MBOM; see Stage Models image below.



UCDth020: Manufacturing System Certification

USE CASE NUMBER: UCDth020	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Manufacturing System Certification*	
Description:	Certification of the manufacturing system to the guidelines set by the United States Department of Defense (DoD) Capture data from the manufacturing machines directly and simulate the manufacturing process for certification

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<table>
<tr><td>Goal:</td><td colspan="3">Data from the manufacturing machines captured directly and simulate the manufacturing process for certification</td></tr>
<tr><td>Use Case Lifecycle Stage:</td><td colspan="3">A-Concept ☐ B-Development ☒ C-Production ☒ D-Utilization ☐
E-Support ☐ F-Retirement ☐</td></tr>
<tr><td>Use Case Frequency:</td><td colspan="3">Daily ☐ Weekly ☐ Monthly ☐ Yearly ☒ Other ☐</td></tr>
<tr><td>Impacted Population:</td><td colspan="3">Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐
More than 1000 ☐</td></tr>
<tr><td>Roles:</td><td colspan="3">Manufacturing Engineer, Facilities Engineer, System Engineer (PLM, Manufacturing Operations Management (MOM), Enterprise Resource Planning (ERP), etc.)</td></tr>
<tr><td>Preconditions:</td><td colspan="3">None</td></tr>
<tr><td>Special Requirements:</td><td colspan="3">None</td></tr>
<tr><td rowspan="5">Normal Course of Events:</td><td></td><td>Action:</td><td>Result:</td></tr>
<tr><td>1.</td><td>Pre-DoD contract award Manufacturing Readiness Level (MRL) determination is made</td><td>DoD MRL assignment is made</td></tr>
<tr><td>2.</td><td>DoD contract award is confirmed</td><td>DoD MRL is confirmed</td></tr>
<tr><td>3.</td><td>DoD contract MRL audit is performed</td><td>MRL audit of compliance is confirmed</td></tr>
<tr><td>4.</td><td>Manufacturing product conformance is verified</td><td>Product conformance is certified</td></tr>
<tr><td>Alternate Course(s) of Events:</td><td colspan="3">None</td></tr>
<tr><td>Data:</td><td colspan="3">DoD MRL Specifications, Original Equipment Manufacturer (OEM) Manufacturing Qualification Specifications, Manufacturing Performance Specifications</td></tr>
<tr><td>Postconditions:</td><td colspan="3">None</td></tr>
</table>

↑ **View Digital Twin List** ↑ **View Digital Thread List**

UCDth021: Long-Term Data Archival and Retrieval

USE CASE NUMBER: UCDth021		**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐	
Use Case Owner: AD PAG		**Associated Use Cases:**	
Use Case Title: *Long-Term Data Archival and Retrieval*			
Description:	Long-term maintenance of data, including archival and retrieval of digital product and technical data Archiving is required until the product's End Of Life (EOL)		
Goal:	Long-term archival of the product data is enabled		
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☐ E-Support ☒ F-Retirement ☒		
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒		
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐		
Roles:	None		
Preconditions:	None		
Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	Customer requirements are received	Customer requirements are reviewed
	2.	Long-term data archival business requirements are defined and documented	Long-term data archival requirements are documented
	3.	Product/Solution is engineered	Data archival requirements are engineered
	4.	Long-term archival system requirements are defined	Long-term archival system requirements are available
	5.	Long-term archival system is designed	Long-term archival system is ready for use
Alternate Course(s) of Events:	None		
Data:			
Postconditions:	None		
Notes:	None		

↑ **View Digital Twin List** ↑ **View Digital Thread List**

UCDth023: Digital Thread Design Certification

USE CASE NUMBER: UCDth023	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐		
Use Case Owner: AD PAG	**Associated Use Cases:**		
Use Case Title: *Digital Thread Design Certification*			
Description:	Certification of designs without multiple prototypes; the digital thread facilitates the digital twin design simulations and certification, replacing the need for constructing prototypes A prototype is developed to validate digital twin simulation accuracy and to support the certification process		
Goal:	Digital thread facilitates the digital twin design simulations and certification		
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐		
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Digital twin simulations are generated on an as-needed basis; the design change rate facilitates the frequency of design certifications		
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐		
Roles:	Design Engineer, System Engineer, Mechanical Engineer, Electrical Engineer, Software Developer, Security Engineering, and other engineering disciplines		
Preconditions:	Customer requirements		
Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	Customer requirements are received	Customer requirements are documented
	2.	Product is designed in accordance with the digital twin and customer requirements	Digital twin product design is defined
	3.	Product's electrical system is engineered	Electrical simulation is conducted to test and evaluate the product's electrical system
	4.	Product's mechanical system is engineered	Mechanical simulation is conducted to test and evaluate the product's mechanical system
	5.	Product's structure is engineered	Structural simulation is conducted to test and evaluate the product's structural integrity

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	6.	Integrated simulation evaluation by team of engineers	Evaluation of simulation results
Alternate Course(s) of Events:	None		
Data:			
Postconditions:	None		

UCDth024: Interactive Production and Maintenance

USE CASE NUMBER: UCDth024	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Interactive Production and Maintenance*	
Description:	Interact with products based on augmented reality using models and technical documentation
Goal:	Interact with products based on augmented reality using models and technical documentation
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☐ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Event-based demand (i.e., Airplane On Ground (AOG)
Impacted Population:	Less than 10 ☒ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐ Depending on the complexity of the event, the participating population ranges from less than 10 to over 100
Roles:	Airline Maintenance Engineer, Airline Mechanic, Airline Operations, Original Equipment Manufacturer (OEM) Field Service Representative (FSR), OEM Service Support Engineer
Preconditions:	Utilization of augmented reality is approved and defined with the customer/operator maintenance repair and overhaul procedures
Special Requirements:	None

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Normal Course of Events: **There are two normal courses:** **1) Scheduled Maintenance** **2) Unscheduled Maintenance** **Scenario in this use case is option 2 – unscheduled maintenance or AOG**		**Action:**	**Result:**
	1.	Customer/operator declares that the product (aircraft) is in an AOG status	Airline Maintenance Engineer, Airline Mechanic, and OEM FSR are dispatched to determine the cause of the AOG status
	2.	Root cause of AOG status is determined	Defined, documented, and augmented reality (Digital Twin) of AOG root cause is established
	3.	OEM is notified of the root cause determination	Augmented reality (Digital Twin) definition of the AOG is sent to the OEM Service Support Engineer
	4.	Owner/Operator/OEM collaborate on a corrective action plan using augmented reality to simulate both the repair and the operational capability	Simulation of corrective action repair and operational status is conducted
	5.	Corrective action documentation is prepared	Product corrective action plan documentation is authorized
	6.	Aircraft is repaired and operational readiness is validated	Product is returned to operational status
Alternate Course(s) of Events:	None		
Data:			
Postconditions:	None		

UCDth025: Design Optimization Production Capabilities

USE CASE NUMBER: UCDth025	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *Design Optimization Production Capabilities*	
Description:	Consider demonstrated manufacturing capabilities for parts design, including life limitations and inspection plan optimization
Goal:	Enable access and traceability between manufacturing capabilities and product design characteristics for life limitations and inspection plan optimization
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐

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Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐		
Roles:	Concession Engineers from production, design, and aftersales		
Preconditions:	Unified software containing all concessions		
Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	(Design) Concession Engineer wants to study the impact of various designs through concessions number evolution and checks the software for an answer	List of the concessions associated with a given part number is received
	2.	(Production) Concession Engineer wants to study the impact of production methods and checks the software for an answer	List of the concessions associated with a given part number is received
	3.	(Aftersales) Concession Engineer wants to study the concessions among the fleet and checks the software for an answer	List of the concessions associated with a given part number is received
	4.	Concession Engineer records findings	Findings are recorded, and additional action is taken if needed
Alternate Course(s) of Events:	Concession Engineer can access the history of the various designs and production methods, as well as the situation of the fleet, all possibly in 3D		
Data:			
Postconditions:	None		
Notes:	None		

UCDth026: Part Authorized Release Certificate (ARC)

USE CASE NUMBER: UCDth026	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG and SAE	**Associated Use Cases:**
Use Case Title: *Part Authorized Release Certificate (ARC)*	

Description:	The purpose of an electronic version of the ARC (eARC) is to provide data to civil aviation authorities and accredited organizations issuing or managing airworthiness for new and return-to-service products
Goal:	Enable a digital thread of part ARC
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☒ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	Manufacturing Engineer, Maintenance Engineer, Mechanic
Preconditions:	None
Special Requirements:	None

Normal Course of Events:

	Action:	Result:
1.	Part is manufactured	eARC is produced for the part
2.	Part is purchased	eARC is made available to purchaser
3.	Part is installed	eARC information is updated
4.	Part is removed for repair	eARC information is updated
5.	Part is repaired	eARC information is updated
6.	Part is disposed of	eARC information is updated
7.	eARC is archived	eARC information is updated

Alternate Course(s) of Events:	None
Data:	See ARC form in Notes
Postconditions:	None

Notes:

Multiple versions of the ARC document exist: Federal Aviation Administration (FAA), European Union Aviation Safety Agency (EASA), Civil Aviation Administration of China (CAAC), etc.

The information collected is similar but does vary between regulatory authorities

Source: SAE International, G-31 Digital Communications Committee

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1. Approving Civil Aviation Authority/Country: FAA/United States	2. **AUTHORIZED RELEASE CERTIFICATE** FAA Form 8130–3, AIRWORTHINESS APPROVAL TAG	3. Form Tracking Number:
4. Organization Name and Address:		5. Work Order/Contract/Invoice Number:

6. Item:	7. Description:	8. Part Number:	9. Quantity:	10. Serial Number:	11. Status/Work:

12. Remarks:

13a. Certifies the items identified above were manufactured in conformity to: ☐ Approved design data and are in a condition for safe operation. ☐ Non-approved design data specified in Block 12.		14a. ☐ 14 CFR 43.9 Return to Service ☐ Other regulation specified in Block 12 Certifies that unless otherwise specified in Block 12, the work identified in Block 11 and described in Block 12 was accomplished in accordance with Title 14, Code of Federal Regulations, part 43 and in respect to that work, the items are approved for return to service.	
13b. Authorized Signature:	13c. Approval/Authorization No.:	14b. Authorized Signature:	14c. Approval/Certificate No.:
13d. Name (Typed or Printed):	13e. Date (dd/mmm/yyyy):	14d. Name (Typed or Printed):	14e. Date (dd/mmm/yyyy):

User/Installer Responsibilities

It is important to understand that the existence of this document alone does not automatically constitute authority to install the aircraft engine/propeller/article.

Where the user/installer performs work in accordance with the national regulations of an airworthiness authority different than the airworthiness authority of the country specified in Block 1, it is essential that the user/installer ensures that his/her airworthiness authority accepts aircraft engine(s)/propeller(s)/article(s) from the airworthiness authority of the country specified in Block 1.

Statements in Blocks 13a and 14a do not constitute installation certification. In all cases, aircraft maintenance records must contain an installation certification issued in accordance with the national regulations by the user/installer before the aircraft may be flown.

FAA Form 8130–3 (02–14) NSN: 0052-00-012-9005

UCDth027: End-to-End Planning

USE CASE NUMBER: UCDth027	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: AD PAG	**Associated Use Cases:**
Use Case Title: *End-to-End Planning*	
Description:	Planning data integration across all lifecycle phases in the production phase, from availability of catalog options to delivery, including logistics
Goal:	Provide access and traceability to enable planning data integration across all lifecycle phases in the production phase
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐

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Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒		
Roles:	System Designer, Designer, Manufacturing Engineering, Manufacturing, Services Support, Programmers, and Extended Stakeholders (Sales), Value Stream Mapping (VSM) Managers		
Preconditions:	Continuity between design, detailed design, manufacturing, and customer services		
Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	End-to-end planning components for the critical path are defined	List of critical components path is compiled
	2.	Main pivot business objects with time attributes are identified	Enterprise data products are defined
	3.	Workflow of the pivot business objects (related to the planning) is identified	Workflow impact is addressed
	4.	Global impact in terms of planning is analyzed	Reports and alerts are generated
Alternate Course(s) of Events:	None		
Data:	Main pivot business objects with time attributes		
Postconditions:	None		
Notes:	None		

↑ **View Digital Twin List** ↑ **View Digital Thread List**

UCDth028: Collaborative Requirements Content Management

USE CASE NUMBER: UCDth028	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: prostep ivip	**Associated Use Cases:**
Use Case Title: *Collaborative Requirements Content Management*	
Description:	Facilitate the definition and management of requirements within a collaborative distributed supply chain Facilitate requirements approval of requirements specifications, include change alerts, and manage change requests and releases Diagram of this use case (referred to as user journey (UJ1)) is provided below in the notes
Goal:	Provide data access and traceability to facilitate requirements definition, management, and approval within a collaborative distributed supply chain
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ As needed
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☒ This is dependent upon the size of the company and organization participating in the conceptualization and development of the product
Roles:	OEM: Design Engineer/Requirements Manager, Lead Engineer, Project Leader, Procurement Agent Partner: Design Engineer/Requirements Manager

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Preconditions:	• Data shall carry a classification (Tag), including intellectual property (IP) ownership • Select data is to be shared (visible, commented modifiable and/or downloadable) • OEM procurement agent and partner contract manager shall be notified of all exchanges • WP6 - Consider strategies for communication of Bill of Features as a basis of collaboration/requirement fulfillment coverage • Traceability of all steps – who/what/when/why (comment and/or linked objects) • Manage requirement maturity status and corresponding modification rights, coverage status • Manage various types of requirements (i.e., customer, functional, FuSaf, internal, standards/normative, regulations, etc.) with different attributes and relations to other entities • Manage a common requirement lifecycle status/workflow view that is either unique for everybody or has unambiguous mapping • Automatically notify subscribers of requirements status updates (for all steps) • Manage IP: control access to shared data based on roles access to the common requirements of the overall product • Address IP protection. • IP ownership shall be defined by the creator and made visible for all on requirements and design artefacts, which are selected to be shared on the platform • Partner may also need to involve their supply chain
Special Requirements:	None

Normal Course of Events:		**Action:**	**Result:**
	1.	Define the requirements (and related features) content and specifications	Content and specifications are defined
	2.	Check consistency and approve the stakeholder requirements	Consistency is checked, and the stakeholder requirements are approved
	3.	Share information objects (requirement (possibly >100%) and/or related Bill of Features) with partner and notify of proposed change.	Information objects are shared with the partner and ?? is notified

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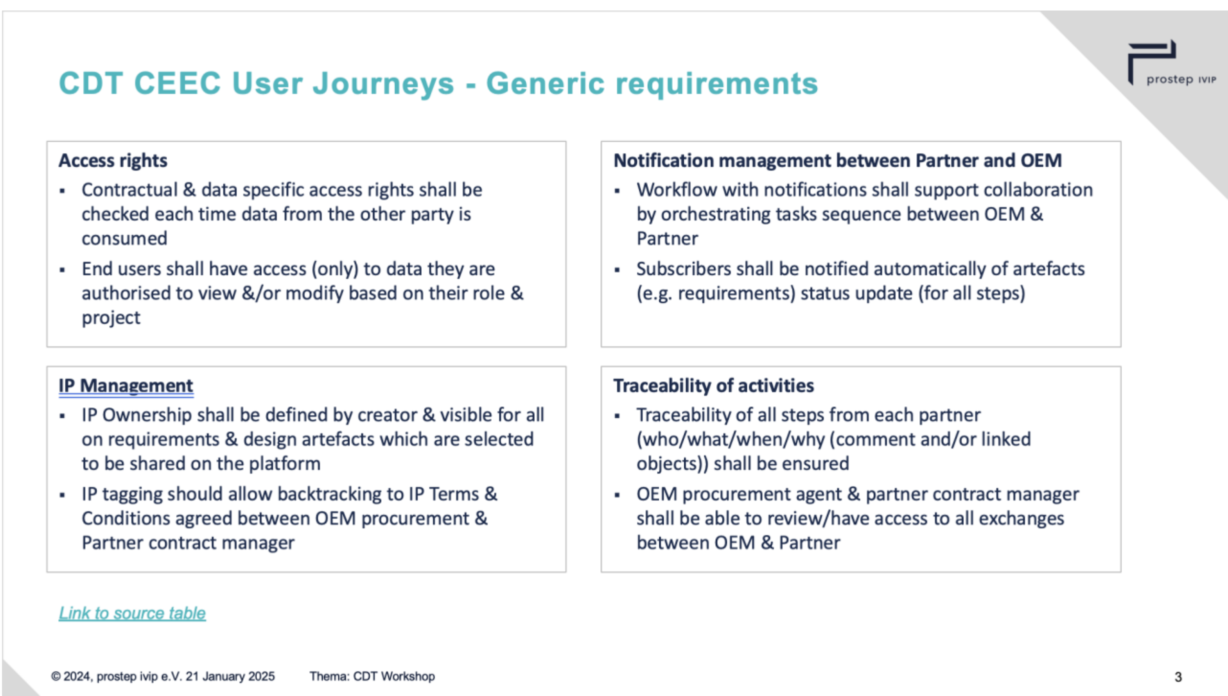
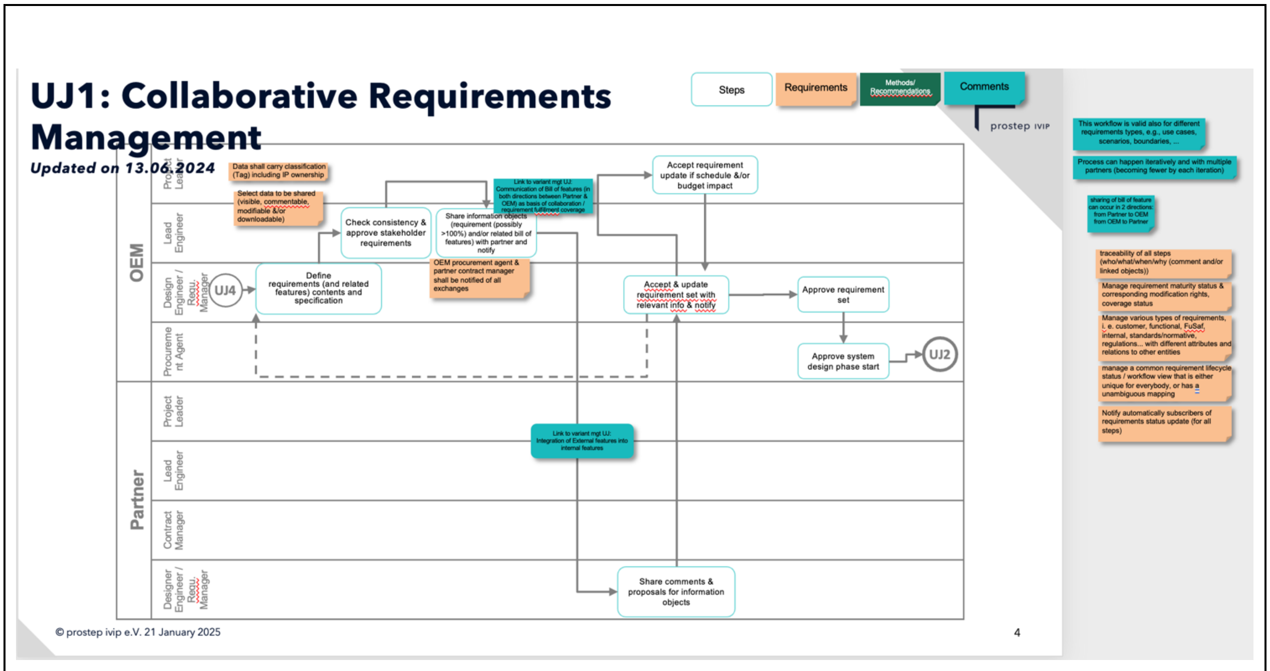
	4.	Share comments and proposals for the information objects	Comments and proposals about the information objects are shared
	5.	Accept and update the requirement set with the relevant information and notify	EITHER 1) Accept requirement update if schedule and/or budget impact OR 2) Approve the requirement set
	6.	If 1 (Accept requirement update if schedule and/or budget impact), repeat Step 5 If 2 (Approve requirement set), go to Step 7	Requirement set is approved
	7.	Approve system design phase start	Begin collaborative system design
Alternate Course(s) of Events:	None		
Data:			
Postconditions:	None		
Notes:			





UCDth029: Collaborative System Design

USE CASE NUMBER: UCDth029	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: prostep ivip	**Associated Use Cases:**

Use Case Title: *Collaborative System Design*	
Description:	Collaboratively define the system architecture and interfaces, merging partners' work products
Goal:	Provide data access and traceability to enable collaborative definition of system architecture and interfaces
Roles:	OEM: System Engineer, Lead Engineer, Design Quality Assessor, Project Leader Partner: Lead Engineer, System Engineer
Preconditions:	• Automated checks to verify integrated model compliance to design standards and quality requirements (i.e., requires high model consistency and alignment on modelling framework and rules across the value chain) • End users shall have access (only) to data they are authorized to view and/or modify based on their role and the project • Connection between the overall collaboration platform and the OEM and partner data management platform • Automated checks to verify the partner model elements' compliance to system design standards and quality requirements

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Special Requirements:	None		
Normal Course of Events:		**Action:**	**Result:**
	1.	Align with the partner system engineer on the modelling approach and framework, system design standards, and modelling specifications	Modelling approach and framework, design standards, and modelling specifications are aligned in coordination with the partner system engineer
	2.	Initiate the system architecture and behavioural models, including the proposal for definition of the interface to sub-systems	Go to Step 3a or Step 4, as applicable
	3a.	Review and share the interface definition proposal	Go to Step 3b
	3b.	Review and update the interface definition proposal (interface control document)	Go to Step 2
	4.	Check for consistency; publish the shareable system design subset, including interfaces for the partner, and provide notification	Shareable system design subset is published, and partner is notified
	5.	Check/translate and share OEM model data with the system engineer	System engineer receives checked/translated OEM model data
	6.	Initiate the sub-system design, and prepare and share comments and proposals for the system design update	Comments and proposals for the system design update are prepared and shared
	7.	Share and link own sub-system architecture elements as a black box, including the interface control document, behaviors, and links to related requirements, with the OEM; share comments and proposals for the requirements/system design update	Sub-system architecture elements are linked with the OEM, and comments, and comments/proposals for requirements/ system design updates are shared
	8.	Integrate all supplied (sub-)systems and analyze the partner's requirements/system design change request(s)	(Sub-)systems are integrated and change request(s) analyzed
	9a.	Check consistency and quality at the vehicle system level	Identified for partner sub-system architecture element update

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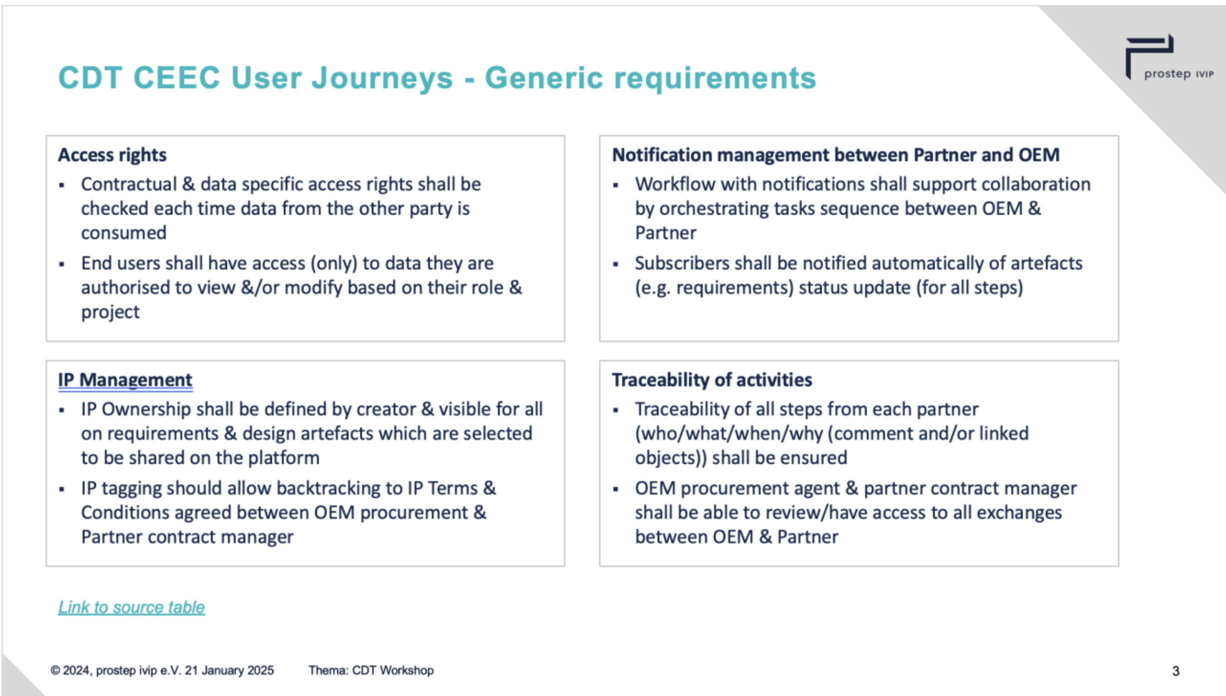
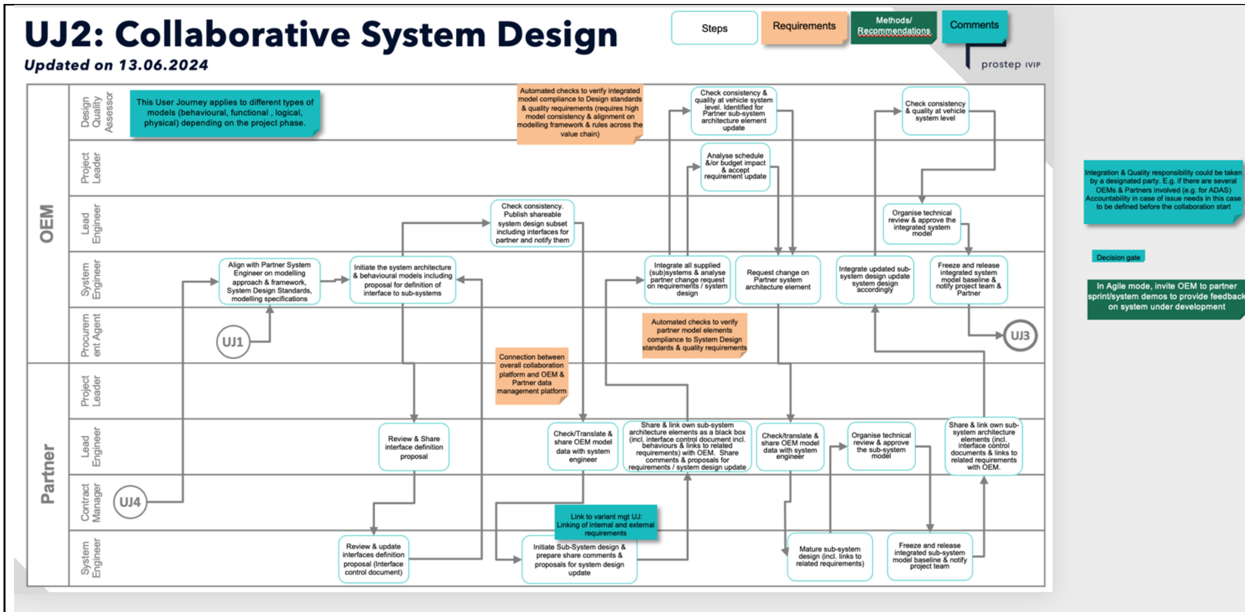
	9b.	Analyze the schedule and/or budget impact, and accept the requirements update	Requirements update accepted
	10.	Request the change on the partner system architecture element	Change request is made
	11.	Check/translate and share the OEM model data with the system engineer	System engineer receives the OEM model data
	12.	Mature the sub-system design, including links to related requirements	Sub-system design is completed
	13.	Organize the technical review, and approve the sub-system	Sub-system is approved
	14.	Freeze and release the integrated sub-system model baseline, and notify the project team	Project team is notified that the integrated sub-system model baseline is released
	15.	Share and link own sub-system architecture elements, including interface control documents and links to related requirements, with the OEM	Sub-system architecture elements are shared and linked with the OEM
	16.	Integrate the updated sub-system design by updating the system design accordingly	Updated sub-system design is integrated into the system design
	17.	Check consistency and quality at the vehicle system level	Consistency and quality are checked at the vehicle system level
	18.	Organize the technical review, and approve the integrated system model	Technical review is organized, and the integrated system model is approved
	19.	Freeze and release the integrated system model baseline, and notify the project team and the partner	Integrated system model baseline is released, and the project team and the partner are notified
Alternate Course(s) of Events:	In Agile mode, invite the OEM to partner sprint/system demos to provide feedback on the system under development		
Data:			
Postconditions:	None		

Notes:

- This use case applies to different types of models (e.g., behavioral, functional, logical, physical), depending on the project phase
- Integration and quality responsibility could be accepted by a designated party (e.g., if several OEMs and partners are involved, such as for Advanced Driver Assistance Systems (ADAS)); in this case, accountability (in case of an issue) needs to be defined before the collaboration starts
- Linking of internal and external requirements





UCDth030: Distributive Collaborative Co-Simulation

USE CASE NUMBER: UCDth030	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: prostep ivip	**Associated Use Cases:**
Use Case Title: *Distributive Collaborative Co-Simulation*	
Description:	Collaboratively integrate the system model with the partners' sub-systems to simulate, develop, and validate performance; collaborative co-simulation is simulation between two or more partners using two different solvers Scope: • Functional performance simulation, non-geometric (i.e., no finite element modelling (FEM)) • Hardware-in-the-Loop (HIL), Driver-in-the-Loop
Goal:	Provide data access and traceability to enable an OEM to collaboratively integrate the system model with the partners' sub-systems
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☒
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ As needed; generally, simulation is performed based on events preceding an activity related to the physical object

<table>
<tr><td>Impacted Population:</td><td colspan="3">Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒
More than 1000 ☐</td></tr>
<tr><td>Roles:</td><td colspan="3">OEM: Lead Engineer, Simulation Expert, Project Leader
Partner: Simulation Expert, Lead Engineer, Data Scientist, Production Engineer, Manufacturing Engineer</td></tr>
<tr><td>Preconditions:</td><td colspan="3">• Using different technology/solver at different partners across the supply chain shall be possible
• Sub-system structure model elements should be shared as a gray box (some parameters shall be modifiable by the OEM)
• Automated checks to verify partner model elements’ compliance to system model standards and quality requirements; if it’s a black/gray box, the check on quality/credibility is limited
• All partners shall be able to change/trace parameters exposed by other partners
• Transverse requirements:
- Ensure simulation, traceability, accountability, and credibility based on inputs from several partners to ensure that it is evaluated and known who is responsible for the results (liability)
- Ensure traceability of all steps—who, what, when, where and why (comment and/or linked objects).
• OEM shall be able to automatically evaluate performance by matching simulation results to the requirement where numerical Key Performance Indicators (KPIs) are available (coverage analysis)</td></tr>
<tr><td>Special Requirements:</td><td colspan="3">None</td></tr>
<tr><td rowspan="6">Normal Course of Events:</td><td></td><td>Action:</td><td>Result:</td></tr>
<tr><td>1.</td><td>Set the target scope for simulation, including requirements, detail, etc.</td><td>Simulation scope is defined</td></tr>
<tr><td>2.</td><td>Align with the partner simulation expert on modelling standards and interfaces</td><td>Modelling standards and interfaces are aligned with the partner simulation expert</td></tr>
<tr><td>3.</td><td>Release the overall system structure model</td><td>Go to Step 4 or 5, as applicable</td></tr>
<tr><td>4.</td><td>Review and update the interface definition proposal</td><td>Go to step 3</td></tr>
<tr><td>5.</td><td>Check/translate the OEM model data</td><td>OEM model data is checked/translated</td></tr>
</table>

	6.	Identify the data (e.g., meta data, evidence) to be shared with the OEM; complete the simulation system structure with own sub-system elements	Data to be shared with OEM is identified and shared, and the simulation system structure is completed
	7.	Approve that the model behavior reflects the component-expected requirements/behavior and release	Model behavior is approved and released
	8.	Integrate the simulation model, execute verification and validation (V&V), perform the simulation and record whether the requirements are met or not	Go to Step 9a and/or 9b, if applicable
	9a.	Request an update on the system architecture	Go to Step 9b, if applicable, and Step 9c
	9b.	Request an update on the requirements	Go to Step 9c
	9c.	Request an update on the system model	System model is updated
	10.	Update the sub-system elements	Sun-system elements are updated
	11.	Approve that the model behavior reflects the component-expected requirements/behavior and release	Model is approved and released
	12.	Integrate the simulation model, execute V&V, perform the simulation and record whether the requirements are met or not	Simulation model is integrated, V&V conducted, simulation performed, and requirements results documented (i.e., met/not met)
	13.	Review and approve the requirements fulfillment	Requirements fulfillment results are reviewed and approved
	14.	Freeze and release the integrated system simulation model and the results baseline, and notify the project team and partner	Integrated system simulation model and results baseline are frozen and released; project team and partner are notified
	15.	Freeze and release the integrated sub-system model baseline, and notify the project team	Integrated sub-system model baseline is frozen and released; project team is notified

Alternate Course(s) of Events:	• Model catalog (index), including a link to relevant models (potentially stored on several repositories) to inform about which models and granularity are made available for the simulation(s) • Consider a detailed and simplified/dummy model, depending on the simulation level • OEM should be able to share a 100% or 150% structure model for the partner to develop the system for a specific product or lineup • Consider strategies for parameters/specifications management together with system model management • Standardize meta models between simulation and test to make planning, decisions, and documentation more interchangeable and reusable between the simulation and the test
Data:	
Postconditions:	None
Notes:	• Integration and quality responsibility could be accepted by a designated party (e.g., if several OEMs and partners are involved, such as for Advanced Driver Assistance Systems (ADAS)); in this case, accountability (in case of an issue) needs to be defined before the collaboration starts. A model shall have a clear objective and clear ownership, access rights, and boundaries • Co-simulation concepts to be formalized: - Option 1: Distributed co-simulation (i.e., intellectual property (IP) and models stay at owner premises) - Option 2: Send models to the common Cloud. In this case, IP rights and ownership need to be guaranteed (e.g., with a license file valid for a given user and until a certain date)

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CDT CEEC User Journeys - Generic requirements

Access rights

- Contractual & data specific access rights shall be checked each time data from the other party is consumed
- End users shall have access (only) to data they are authorised to view &/or modify based on their role & project

Notification management between Partner and OEM

- Workflow with notifications shall support collaboration by orchestrating tasks sequence between OEM & Partner
- Subscribers shall be notified automatically of artefacts (e.g. requirements) status update (for all steps)

IP Management

- IP Ownership shall be defined by creator & visible for all on requirements & design artefacts which are selected to be shared on the platform
- IP tagging should allow backtracking to IP Terms & Conditions agreed between OEM procurement & Partner contract manager

Traceability of activities

- Traceability of all steps from each partner (who/what/when/why (comment and/or linked objects)) shall be ensured
- OEM procurement agent & partner contract manager shall be able to review/have access to all exchanges between OEM & Partner

Link to source table

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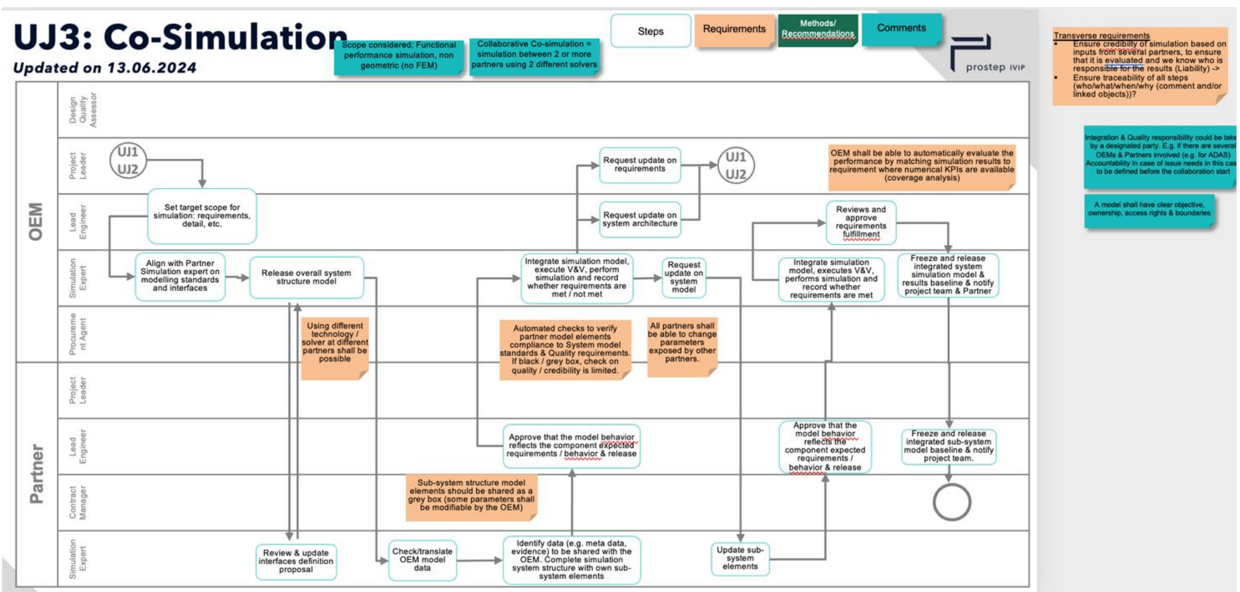

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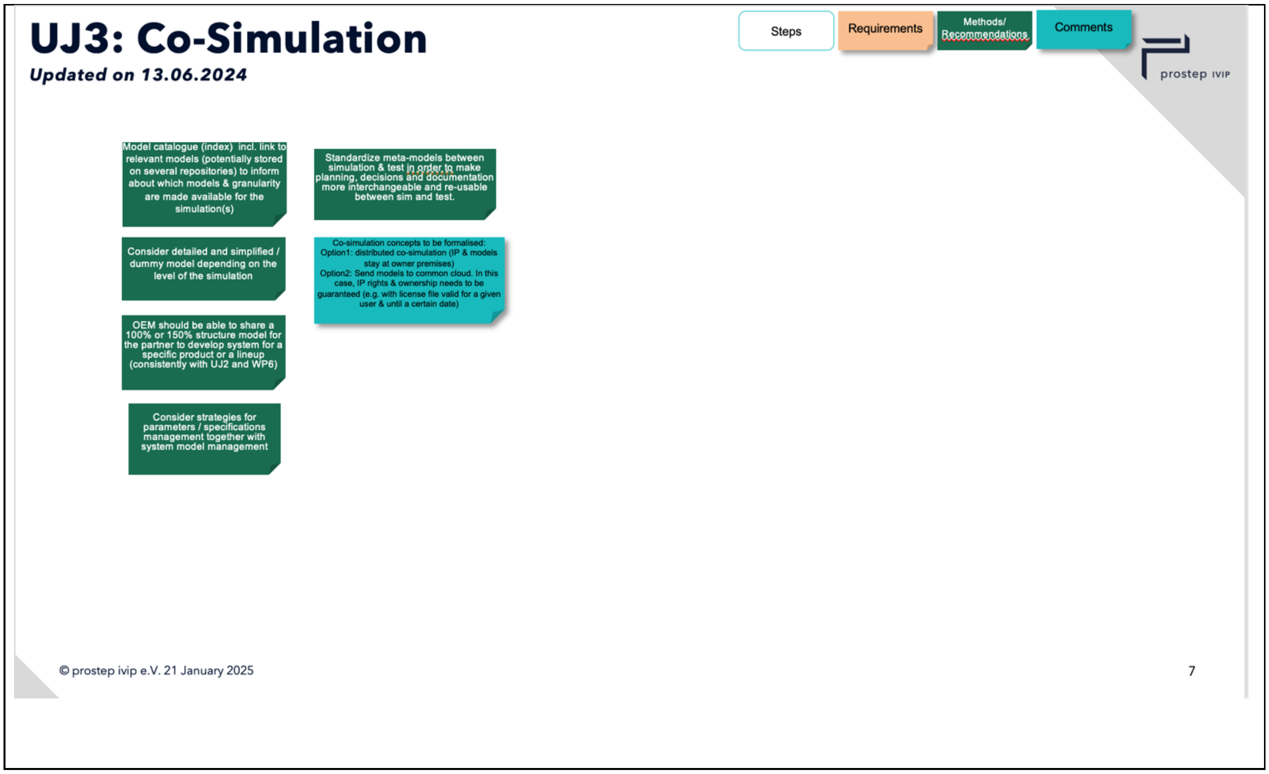

UCDth031: Collaboration Model Setup

USE CASE NUMBER: UCDth031	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: prostep ivip	**Associated Use Cases:**
Use Case Title: *Collaboration Model Setup*	
Description:	Define and set up collaboration models, roles and responsibilities, access rights, information technology (IT) architecture, and archiving models
Goal:	Provide data access and traceability to enable an OEM to set up collaboration models, and associated governance and technical elements
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☐ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐ This collaboration model, once established, presumably at project initiation, will be used throughout the lifecycle of the product
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	OEM: Design Quality Assessor, Procurement Agent, Lead Engineer, Project Leader, Specialist Partner: Project Leader, Lead Engineer, Contract Manager

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<table>
<tr><td>Preconditions:</td><td colspan="3">

At each data exchange between the OEM and the partner, access rights shall be checked
Versioning capability and consideration is provided in the access rights and roles concept
Manage Intellectual Property (IP): Control access on shared data based on roles access to the common requirements of the overall product
IP ownership shall be defined by the creator and made visible for all on the requirements and design artefacts, which are selected to be shared on the platform
End users shall have access (only) to data they are authorized to view and/or modify based on their role and the project
Automatically notify the subscribers of the artefacts (e.g., requirements) of the status update (for all steps)
Ensure traceability of all steps—who, what, when, why (comment and/or linked objects)

</td></tr>
<tr><td>Special Requirements:</td><td colspan="3">None</td></tr>
<tr><td rowspan="4">Normal Course of Events:</td><td></td><td>Action:</td><td>Result:</td></tr>
<tr><td>1.</td><td>Confirm the partners and work content:

Propose the contractual framework and agree with the partner contract manager; set up the contract
Approve disclosure to the partner supply chain and provide the corresponding rules
Define the liability principles
Agree on the quality requirements, as well as the integration and quality assurance roles, responsibilities, and accountability
</td><td>Partners and work content are confirmed as agreements are reached</td></tr>
<tr><td>2.</td><td>Provide the quality requirements, etc. to go into the contractual terms</td><td>Contractual terms are provided</td></tr>
<tr><td>3.</td><td>Share comments about and agree on the contractual framework:

Request disclosure to the partner supply chain
Sign contract
</td><td>Contractual framework is defined, disclosure to the partner supply chain is provided, and the contract is signed</td></tr>
</table>

	4.	Propose the way-of-working method/collaboration framework, including the following: • Data structure/formats and compliance to international standards • Collaboration workspace/information transfer mechanisms • Process for data exchange rules • Process solving issues and escalations	Way-of-working method/collaboration framework is proposed
	5.	Agree on the collaboration framework	Collaboration framework is agreed upon
	6.	Set up interfaces and organization: • Nominate focal points (responsible for overall coordination of activities related to the program) • Designate an appropriate representative, who is responsible for project collaboration space creation, in the case of (partially) centralized architecture) setup of interfaces/data flows, and access rights mechanisms • Define hardware setup; software setup; account setup and role assignment; creation, maintenance, and deletion of user accounts; data archiving/data retention rules • Define a support system	Interfaces and organization are established
	7.	Notify the partner	Partner is notified of setup and organization
	8.	Check data exhaustivity versus the contractual requirements; identify and request missing partner data	After thorough data checking, missing partner data is requested
	9.	Complete the missing data, and notify the OEM	Missing data is completed, and OEM is notified
	10.	Archive data (i.e., make the data available for the OEM and partner in read-only status for the mid-term after collaboration phase closure)	Data is archived

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	11.	Approve closure of the project or collaboration phase with the partner	Project or collaboration phase closure with the partner is approved
	12.	Close access to the collaboration platform, and archive the contents; notify the partner	Collaboration platform is closed, contents are archived, and the partner is notified
Alternate Course(s) of Events:	None		
Data:			
Postconditions:	None		

Notes:

This use case considers the OEM-Partner collaboration; in the case of OEM-OEM or Partner-Partner, some steps would need to be adapted, but the core steps would remain the same with several partners; this use case may run in parallel with several partners

Align on exchange (format) of features, solution space (available variance)/features, common language (mapping of internal and external views), and variability model (model versus calculated discrete variants); share the bill of features as the basis of collaboration requirement fulfillment coverage

Contractual framework shall cover following aspects:

1. Applicable regulations are identified, supporting the project (consider worldwide business relationships, governments, and regional authorities)
2. Statement of Work has been defined (work scope defines category of supplier relationship, such as design and build to spec, design or other intellectual services, equipment)
3. Export control and intellectual property (IP) agreement
4. Data exchange rules and processes
5. Project management terms
6. Monitoring and management of contract execution and contractual coverage of evolution requests
7. Anticipation and mitigation of contractual risks (shared risk analysis, mitigation action plan, contract amendment)
8. Review of contractual IP expectations for each participating stakeholder and partner
9. Expansion upon contractually defined IP protection
10. Definition and implementation of IP protection-compliant processes for the collaboration

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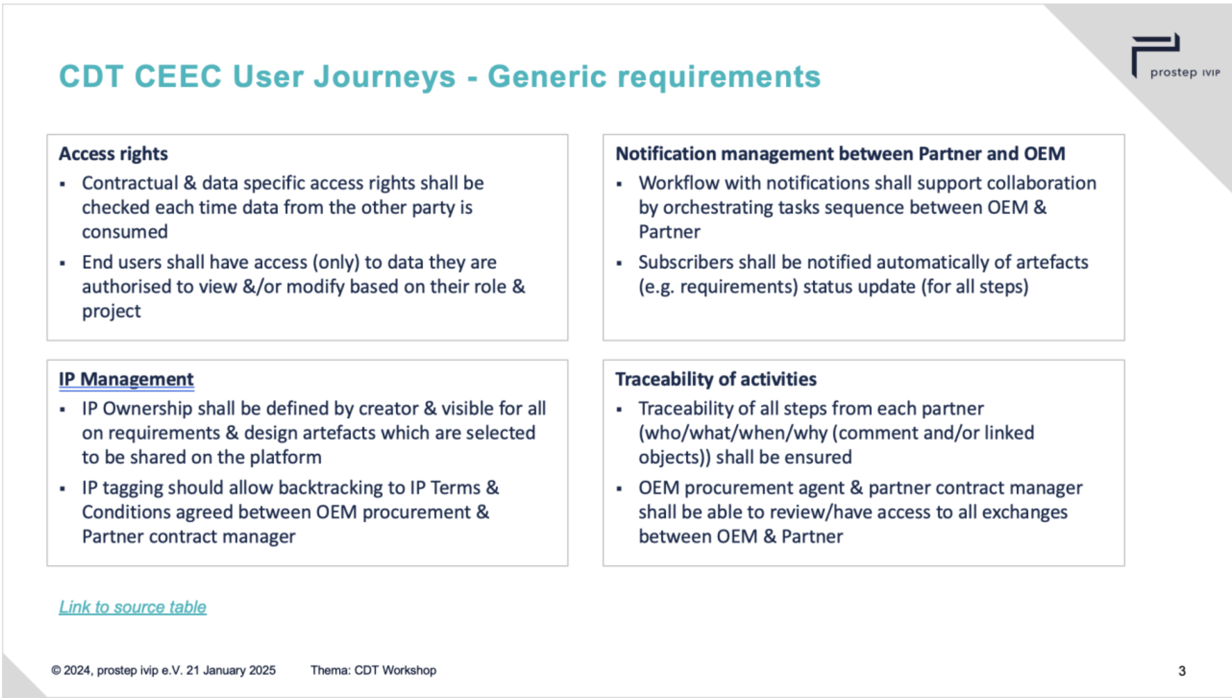

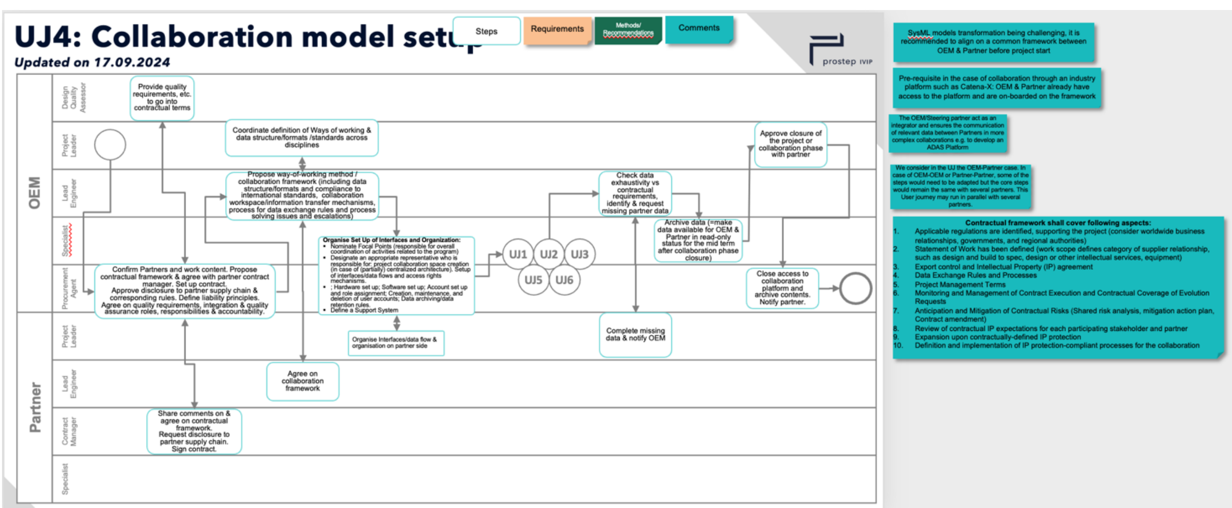

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UCDth032: Collaborative Integration and Tests

USE CASE NUMBER: UCDth032	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: prostep ivip	**Associated Use Cases:**
Use Case Title: *Collaborative Integration and Tests*	
Description:	Improved integration of components into prototypes and automatic preparation of Hardware-in-the-Loop (HiL) tests
Goal:	Provide data access and traceability to enable improved component integration and automatic preparation of HiL tests
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☒ Monthly ☐ Yearly ☐ Other ☐ Event based frequency – Expected weekly
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	OEM: Lead Engineer, Testing Expert, Project Leader Partner: Testing Expert, Lead Engineer
Preconditions:	• To Be Confirmed (TBC): OEM should be able to share a 100% or 150% structure model for the partner to develop a system for a specific product or a lineup • OEM shall be able to automatically evaluate the performance by matching test results to a requirement where numerical Key Performance Indicators (KPIs) are available (coverage analysis)
Special Requirements:	None

Normal Course of Events:

	Action:	**Result:**
1.	Set the target objectives and the scope for testing (e.g., requirements, detail, etc.)	Testing objectives and scope are set
2.	Align with the partner testing expert on the testing scope and objectives, as well as the product configuration and principles	Work with the partner testing expert begins; the scope, objectives, product configuration, and principles are addressed
3.	Review and update the testing scope and objectives and the product configuration and principles	Scope, objectives, product configuration, and principles are reviewed and updated

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	4.	Release the overall system prototype configuration definition, including mechanical, electrical and electronics (E/E), and software (SW) components	Overall system prototype is released
	5.	Manufacture and assemble the system prototype	System prototype is manufactured and assembled
	6.	Define the sub-system prototype configuration and testing parameters/environment based on the OEM requirements and/or the system prototype configuration, including mechanical, , electrical and electronics (E/E), and software (SW) components	Subsystem prototype configuration and testing are defined
	7.	Manufacture and assemble the sub-system prototype components (e.g., SW, electronic control unit (ECU), mechanical parts); perform the sub-system test or simulation; deliver the physical test sub-system prototype together with the configuration data and test parameters to the OEM	Sub-system prototype components are manufactured and assembled, the sub-system testing or simulation is performed, and the physical test sub-system prototype and configuration data and test parameters are delivered to the OEM
	8.	Approve that the test sub-system behavior reflects the expected requirements/behavior and release	Test sub-system is approved
	9.	Integrate the system prototype, perform HiL tests, analyze the results, and record if requirements are not met	System prototype is integrated, HiL testing is performed, and the results are analyzed and recorded
	10.	Request an update to the system architecture and/or design	Update of the system architecture and/or design is received
	11.	Request an update to the requirements	Update of the requirements is received
	12.	Identify the need to update the sub-system design, and request a sub-system design update	Need for a sub-system design update is identified and requested
	13.	Update the sub-system design	Sub-system design is updated
	14.	(Re)manufacture and assemble the sub-system prototype components; perform the sub-system test or simulation; deliver the physical test sub-system prototype together with the configuration data and test parameters to the OEM	Sub-system prototype components are (re)manufactured and assembled; the testing or simulation is performed; the physical test sub-system prototype and configuration data and test parameters are delivered to the OEM

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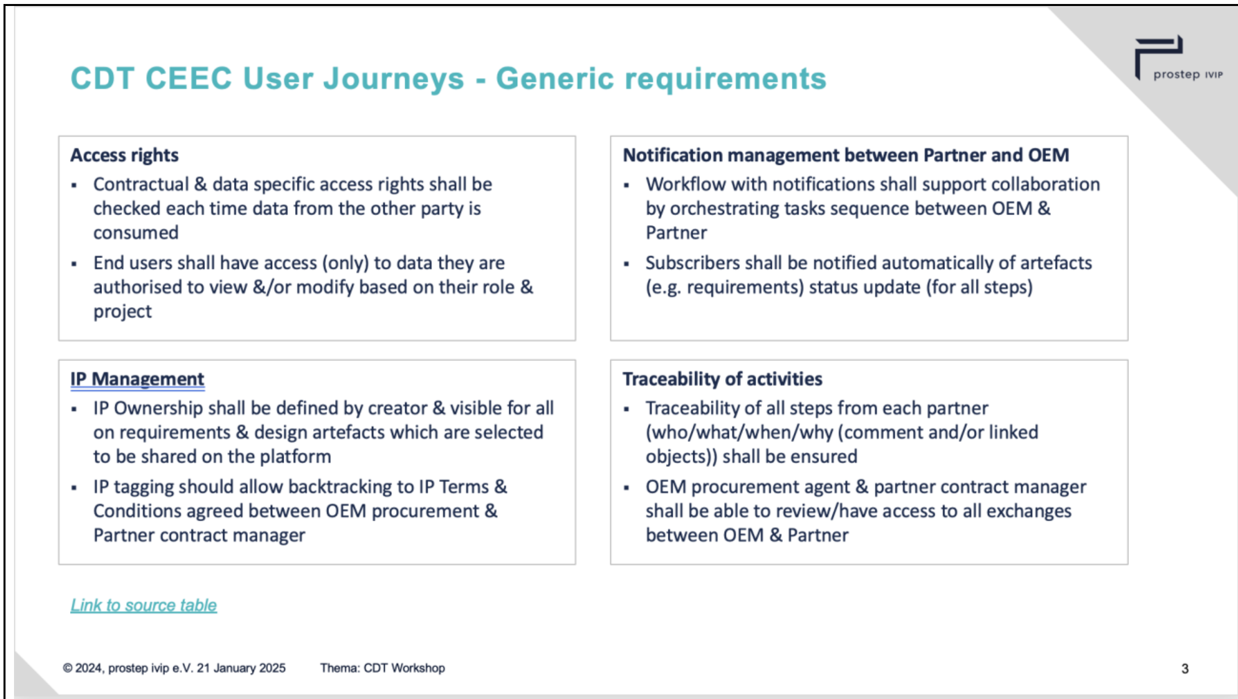
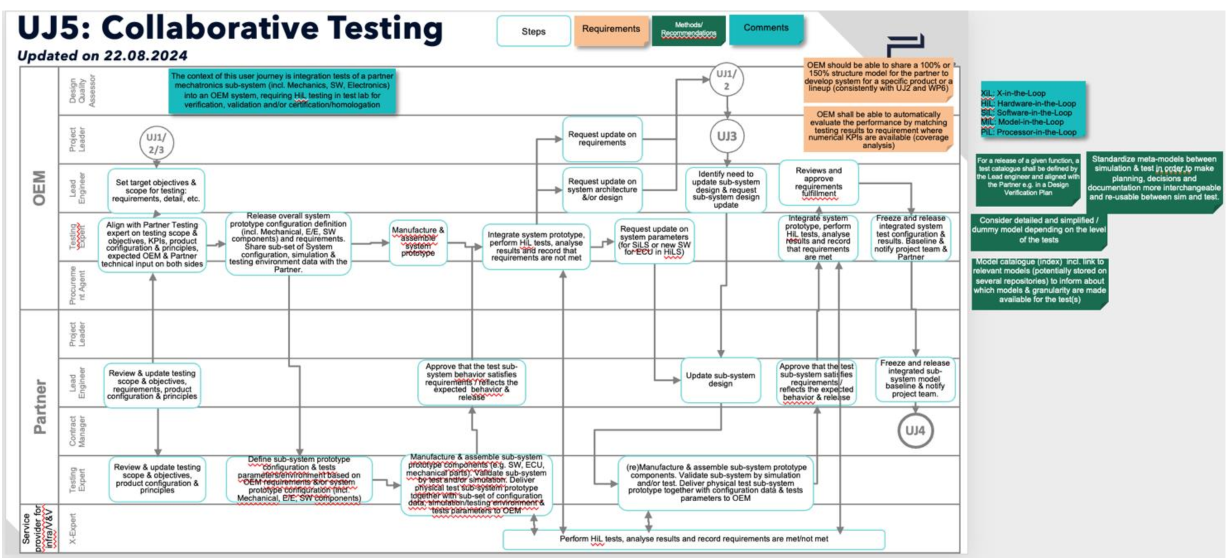
	15.	Approve that the test sub-system behavior reflects the expected requirements/behavior and release	Approval and release of the test sub-system
	16.	Integrate the system prototype, perform the HiL tests, analyze the results, and record that the requirements are met	System prototype is integrated, HiL tested, and the results are analyzed and recorded
	17.	Review and approve the requirements fulfillment	Requirements fulfillment is reviewed and approved
	18.	Freeze and release the integrated system test model and results baseline, and notify the project team and the partner	Integrated system test model and results baseline are frozen and released, and the project team and partner are notified
	19.	Freeze and release the integrated sub-system model baseline, and notify the project team	Integrated sub-system model baseline is frozen ad released, and the project team is notified
Alternate Course(s) of Events:	Standardize meta models between the simulation and test to make planning, decisions, and documentation more interchangeable and reusable between the simulation and the test		
Data:			
Postconditions:	None		
Notes:	• This use case applies to tests performed along the project from simulation to XiL to test labs to the road • Verification, validation, and certification/homologation • This use case applies to multi-discipline systems, including mechanics, SW, and electronics		





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UCDth033: Collaborative Manufacturing Engineering

USE CASE NUMBER: UCDth033	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐	
Use Case Owner: prostep ivip	**Associated Use Cases:**	
Use Case Title: *Collaborative Manufacturing Engineering*		
Description:	Collaboratively define and share data on production process, equipment, and assets	
Goal:	Provide data access and traceability to enable OEM and partners to collaboratively define and share data on production process, equipment, and assets	

UCDth046: OpenCLM - Cross System / Domain Impact Analysis

USE CASE NUMBER: UCDth046	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐	
Use Case Owner: PROSTEP AG	**Associated Use Cases:**	
Use Case Title: *OpenCLM - Cross System / Domain Impact Analysis*		
Description:	Utilizing OpenCLM with connectors to various other systems demonstrates OpenCLM operation, process templates, linking data from external sources, evaluating impact analysis, visualizing impacts through data graph visualization Separate software solutions exist that are data repositories and Authoritative Sources of Truth (ASOT) for domain data; utilizing OpenCLM with connectors to PLM, MBSE, ALM, ERP, or other systems demonstrates OpenCLM operation, process templates, linking data from external sources, evaluating impact analysis, and visualizing impacts though data graph visualization	
Goal:	Provide a means to determine precise system impact analysis of changes across all domain artifacts	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐	
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐	
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐	
Roles:	Systems Engineer	
Preconditions:	Data is authored and managed within multiple software solutions from different vendors. Integration connectivity is required for each domain tool.	

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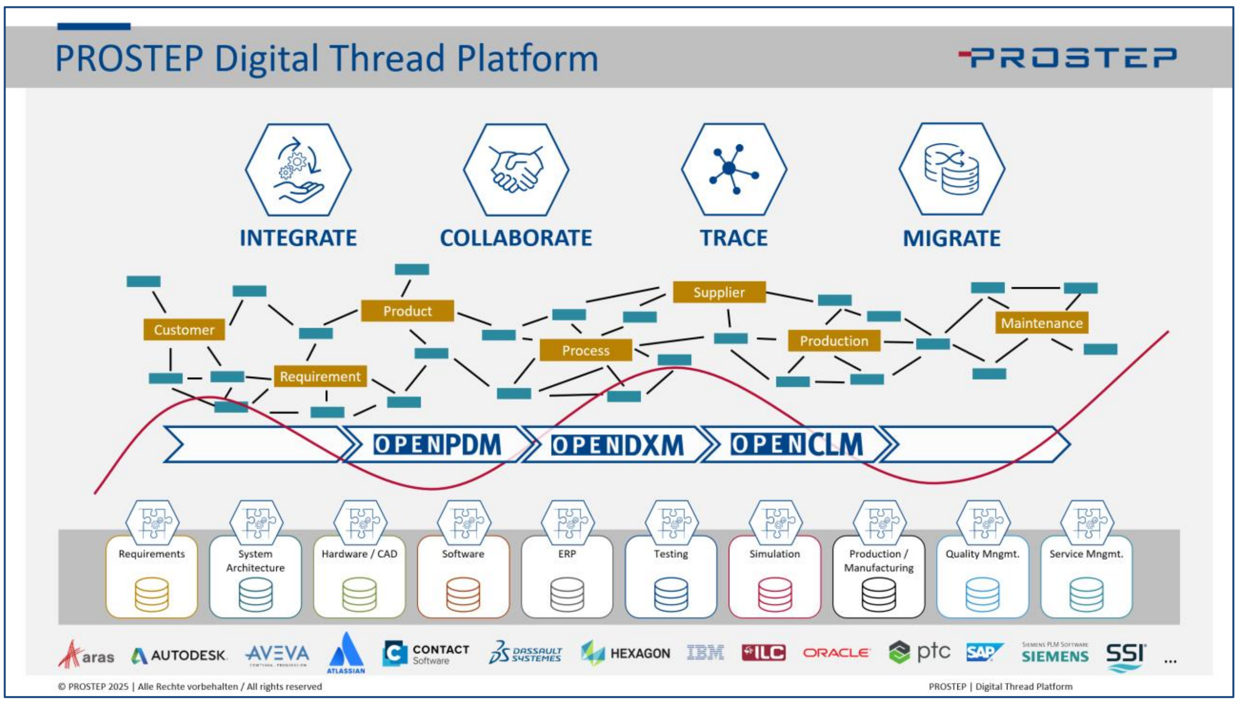
Normal Course of Events:		**Action:**	**Result:**
	1.	Configuration items are created and linked directly through integration to ASOT data within various systems	Model for impact is established that includes directly integrated artifacts
	2.	Changes within the system occur and impacts across domain solutions are to be analyzed	Impact of change across all integrated solutions is evaluated yielding analysis
Alternate Course(s) of Events:	Manual evaluation from each independent system stakeholder without integration		
Data:			
Notes:			



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UCDth047: OpenCLM - Integrated Enterprise Configuration Lifecycle Management and Baselining

USE CASE NUMBER: UCDth047	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner: PROSTEP AG	**Associated Use Cases:**
Use Case Title: *OpenCLM - Integrated Enterprise Configuration Lifecycle Management (CLM) and Baselining*	
Description:	Data representing the Authoritative Source of Truth (ASOT) for multiple domain tools is distributed between multiple repositories Configuration management of the system requires alignment of artifacts controlled in each system at product milestones, such as releases, builds, or other snapshots in time OpenCLM is a tool for creating the digital thread though integrated data; this allows for linking data from connected systems, provides semantic relationships between them, and creates immutable baselines of the data in OpenCLM for permanent configuration records
Goal:	The data, including system-to-system relationships and baselines, can then be referenced for enterprise configuration management
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☒ D-Utilization ☒ E-Support ☒ F-Retirement ☐
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Continuous utilization – On demand
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☒ More than 1000 ☐
Roles:	Systems Engineer
Preconditions:	Configuration management of individual domain tools is done within separate systems, which may include Requirements, Software, Mechanical, System Definition, Testing and Validation, Manufacturing, Sustainment Data and more

Normal Course of Events:

	Action:	Result:
1.	Data from separate systems is identified and integrated to the CLM tool	Up-to-date configuration of multiple domain tools is created and related in the CLM tool
2.	A baseline of the system is created to preserve the system configuration at the maturity state, date, or other milestone	Complete system is captured within the baseline, including artifacts linked to the ASOT tool

Alternate Course(s) of Events:	Manual tracking and configuration management between data repositories

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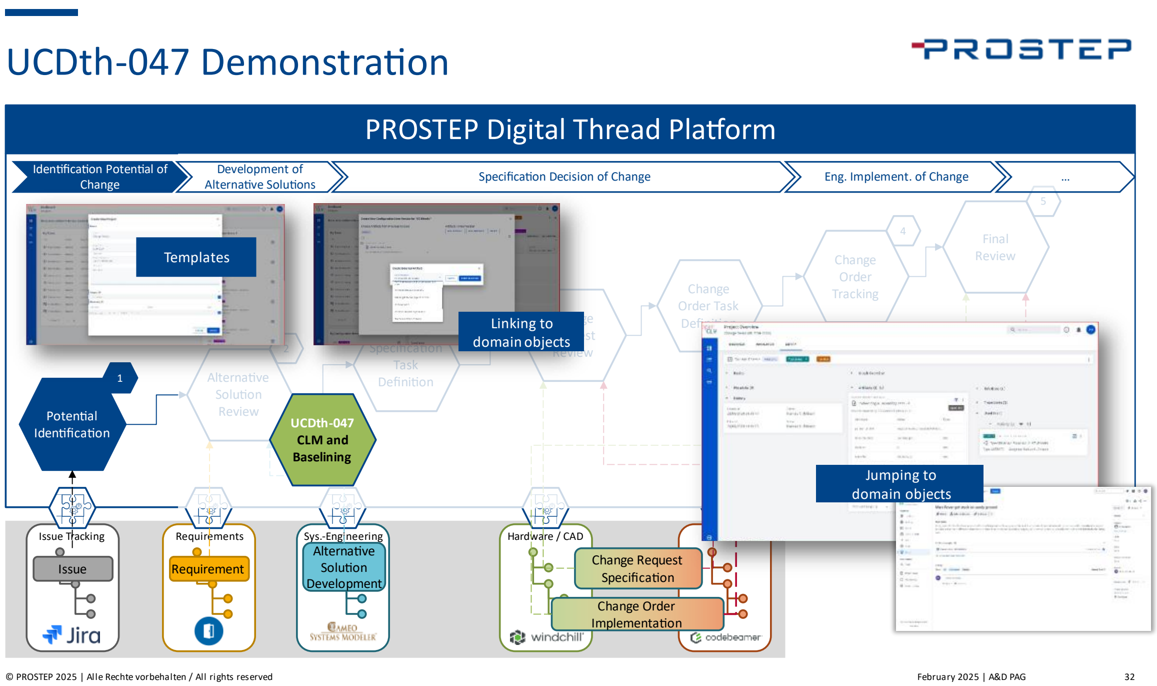
Data:	
Notes:	



UCDth048: OpenPDM - Cameo PLM Integration

USE CASE NUMBER: UCDth048	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐	
Use Case Owner: PROSTEP AG	**Associated Use Cases:**	
Use Case Title: *OpenPDM - Cameo PLM Integration*		
Description:	A variety of integration solutions for DS Cameo include a Cameo client plugin, integration through Open Services for Lifecycle Collaboration (OSLC) for the Cameo Datahub, and Teamwork Cloud Connector integration Integration of the Authoritative Source of Truth (ASOT) data with the primary model-based systems engineering tool	
Goal:	Enable verification and validation (V&V) though integration of ASOT data with the MBSE tool	
Use Case Lifecycle Stage:	A-Concept ☒ B-Development ☒ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐	
Use Case Frequency:	Daily ☒ Weekly ☐ Monthly ☐ Yearly ☐ Other ☒ Continuous utilization – On demand	

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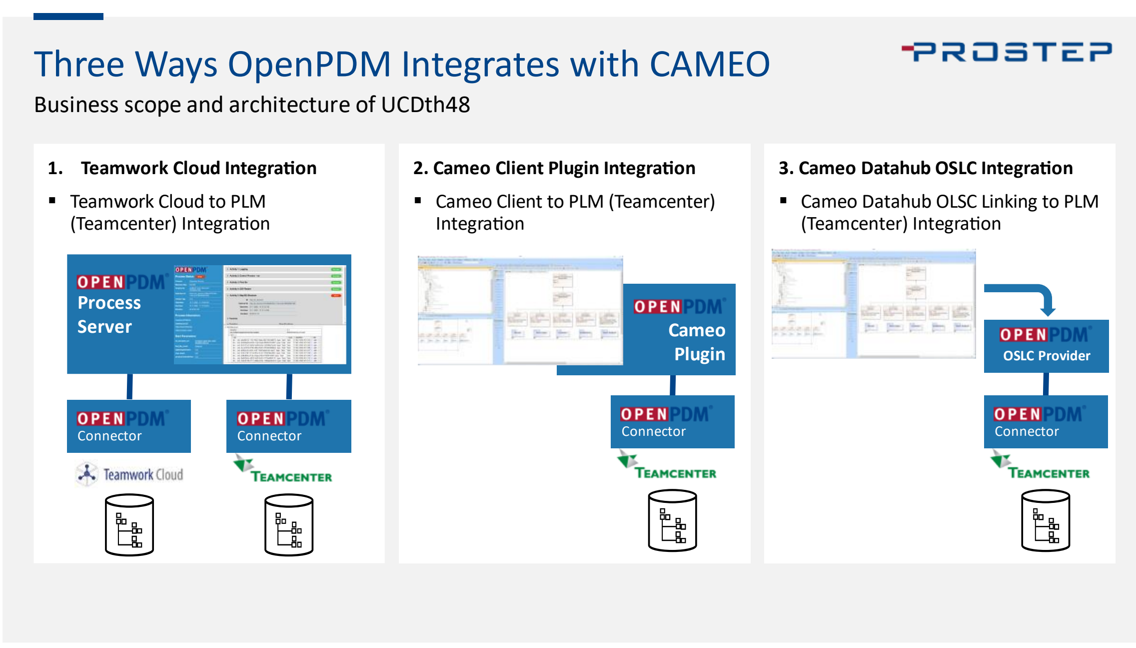
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☒ Between 100 and 1000 ☐ More than 1000 ☐		
Roles:	Systems Engineer		
Preconditions:	• MBSE tools are utilized for developing and validating dependencies between components of systems; these data components are from different sources and can be incorporated into the system • This integration can be accomplished by replicating data into the MBSE tool authored and maintained in another data repository, thereby linking data from external sources to reference key attributes used within the model		
Normal Course of Events:		**Action:**	**Result:**
	1.	System Engineer develops the model, including Requirement, Functional, Logical, and Physical (RFLP) components that ASOT is defined within multiple, separated software solutions	System model within the MBSE solution is developed with data from ASOT repositories and/or linked to the original artifacts
	2.	Validation performed in the MBSE tool is completed with referenced data	Validation is done against datasets representing the system and ensuring correct input and an effective digital thread
Alternate Course(s) of Events:	• Develop the model without linking or referencing data • Manually create and update the data within the MBSE tool		
Data:			
Notes:			



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- Set the direction for the aerospace & defense industry on PLM-related topics that matter to members (*including promoting, not duplicating, the work of standards bodies*)
- Promote common industry PLM processes and practices
- Define requirements for common interest PLM-related capabilities
- Communicate with a unified voice to PLM solution providers
- Sponsor collaborative PLM research on prioritized industry and technology topics

CIMdata administers Group operations, coordinates research, and manages the progression of policy formulation.

About CIMdata

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Appendix: Digital Twin-Digital Thread Use Case Templates

Digital Twin Use Case Template

The following template was used to define and describe ea ch digital twin use case to be demonstrated.

USE CASE NUMBER: UCDtwXXX	**Use Case Type: Digital Thread** ☐ **Digital Twin** ☒
Use Case Owner:	**Associated Use Cases:**
Use Case Title:	
Description:	
Goal:	
Data:	
Digital Twin Development	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	
Preconditions:	
Special Requirements:	
Postconditions:	
Digital Twin Utilization	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐

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Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	
Preconditions:	
Special Requirements:	
Postconditions:	
Notes:	

Template Field Definitions

Field Name	Definition
USE CASE NUMBER	Unique identifier assigned by the Project Coordinator.
Use Case Type	Designation of use case as Digital Thread or Digital Twin.
Use Case Owner	The designated individual or entity responsible for drafting and managing the review and refinement of the use case definition.
Associated Use Cases	USE CASE NUMBER of any digital thread or digital twin use case(s) that creates or extracts and associates the digital twin data.
Use Case Title	A concise and descriptive name summarizing the nature of the use case.
Description	A succinct statement of the scope and purpose of the use case.
Goal	The intended outcomes and business value to be achieved by execution of the use case.
Data	The data that is accessed, manipulated, and associated to create, maintain, and consume a digital twin within the use case scenario.
Use Case Lifecycle Stage	The stage or stages of the product lifecycle during which the use case is created or consumed: A-Concept, B-Development, C-Production, D-Utilization, E-Support, F-Retirement.
Use Case Frequency	How often the use case is executed within a defined period. Some use cases are executed dozens of times a day. Others are executed only infrequently.
Impacted Population	How many people execute the use case within a defined period. Some use cases are executed by many people. Others are executed by a small number.

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Field Name	Definition
Roles	The job function of individuals who execute the use case. Some roles may be variants within Engineering, Manufacturing, Service, Purchasing, or Finance. Some may be digital twin specialists or computer programmers.
Preconditions	The conditions or circumstances that must be fulfilled or exist before executing the use case.
Special Requirements	Additional specific conditions, needs, or unique considerations beyond the normal prerequisites or constraints for executing the use case.
Postconditions	The conditions or circumstances that are required to be true after the successful execution of the use case.
Notes	Additional remarks, comments, or contextual details, including figures and illustrations, pertinent to the use case, to aid in comprehension and understanding.

Digital Thread Use Case Template

The following template was used to define and describe each digital thread use case to be demonstrated.

USE CASE NUMBER: UCDth0XX	**Use Case Type: Digital Thread** ☒ **Digital Twin** ☐
Use Case Owner:	**Associated Use Cases:**
Use Case Title:	
Description:	
Goal:	
Use Case Lifecycle Stage:	A-Concept ☐ B-Development ☐ C-Production ☐ D-Utilization ☐ E-Support ☐ F-Retirement ☐
Use Case Frequency:	Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Other ☐
Impacted Population:	Less than 10 ☐ Between 10 and 100 ☐ Between 100 and 1000 ☐ More than 1000 ☐
Roles:	
Preconditions:	
Special Requirements:	

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Normal Course of Events:		**Action:**	**Result:**
	1.		
	2.		
	3.		
	4.		
Alternate Course(s) of Events:			
Data:			
Postconditions:			
Notes:			

Template Field Definitions

Field Name	**Definition**
USE CASE NUMBER	Unique identifier assigned by the Project Coordinator.
Use Case Type	Designation of use case as Digital Thread or Digital Twin.
Use Case Owner	The designated individual or entity responsible for drafting and managing the review and refinement of the use case definition.
Associated Use Cases	USE CASE NUMBER of any digital thread or digital twin use case(s) that creates or extracts and associates the digital thread data.
Use Case Title	A concise and descriptive name summarizing the nature of the use case.
Description	A succinct statement of the scope and purpose of the use case.
Goal	The intended outcomes and business value to be achieved by execution of the use case.
Use Case Lifecycle Stage	The stage or stages of the product lifecycle during which the use case is created or consumed: A-Concept, B-Development, C-Production, D-Utilization, E-Support, F-Retirement.
Use Case Frequency	How often the use case is executed within a defined period. Some use cases are executed dozens of times a day. Others are executed only infrequently.
Impacted Population	How many people execute the use case within a defined period. Some use cases are executed by many people. Others are executed by a small number.
Roles	The job function of individuals who execute the use case. Some roles may be variants within Engineering, Manufacturing, Service, Purchasing, or Finance. Some may be digital thread specialists or computer programmers.

↑ **View Digital Twin List** ↑ **View Digital Thread List**

Field Name	Definition
Preconditions	The conditions or circumstances that must be fulfilled or exist before executing the use case.
Special Requirements	Additional specific conditions, needs, or unique considerations beyond the normal prerequisites or constraints for executing the use case.
Normal Course of Events	The standard sequence of actions and their corresponding outcomes, illustrating the expected progression of a specific scenario within a project or system.
Alternate Course(s) of Events	The deviations from the standard sequence of actions and outcomes, presenting alternative paths or scenarios within a project or system when specific conditions or actions diverge from the norm.
Data	The data that is accessed, manipulated, and associated to create, maintain, and consume a digital thread within the use case scenario.
Postconditions	The conditions or circumstances that are required to be true after the successful execution of the use case.
Notes	Additional remarks, comments, or contextual details, including figures and illustrations, pertinent to the use case, to aid in comprehension and understanding.

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