International Council on Systems Engineering
A better world through a systems approach

Paper 147 | Session 5.3.3

A System-of-Systems Modeling, Simulation and Data Analytics Framework for Resilient Sustainment and Support Readiness Strategies

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Bruno JOFFRET, Gan WANG, Berenger WINCKLER
DASSAULT SYSTEMES

Ready for Readiness?

Gauthier FANMUY

Director CATIA Cyber Systems Industry Process Expert

Helping Industry to understand the value of Virtual Twin Experiences and Model-Based Systems Engineering. Certified OMG UAF Model user.

Guillaume BELLONCLE

Director CATIA MBSE Strategic Engagements

Advising and supporting Clients in their Systems Engineering transformation and fostering an ecosystem of specialized key Partners in MBSE.

DASSAULT SYSTEMES | Company Overview

Accelerate sustainable innovation with Virtual Twin and 3D UNIVERSES

- **Software Solutions** for Model-based Systems Engineering, 3D Modeling & Simulation, Product Lifecycle Management, Collaboration and Data Science
- Created in **1981**
- 6.2 b€ **revenues** (FY 2024, Non-IFRS)
- 22 500 **Employees** in 130+ countries
- 300 000 **Enterprise Customers**
- 45 million **Users**, 17 000 **Partners** (Technology, Consulting, Sales, Integration & Services)

Deliver software solutions supporting 12 industries

- Transportation & Mobility
- Aerospace & Defense
- Consumer Packaged Goods & Retail
- Marine & Offshore
- Industrial Equipment
- High Tech
- Home & Lifestyle
- Architecture, Engineering & Construction
- Infrastructure, Energy & Materials
- Business Services
- Cities & Public Services
- Life Sciences & Healthcare

Collaborate with Industry Leaders

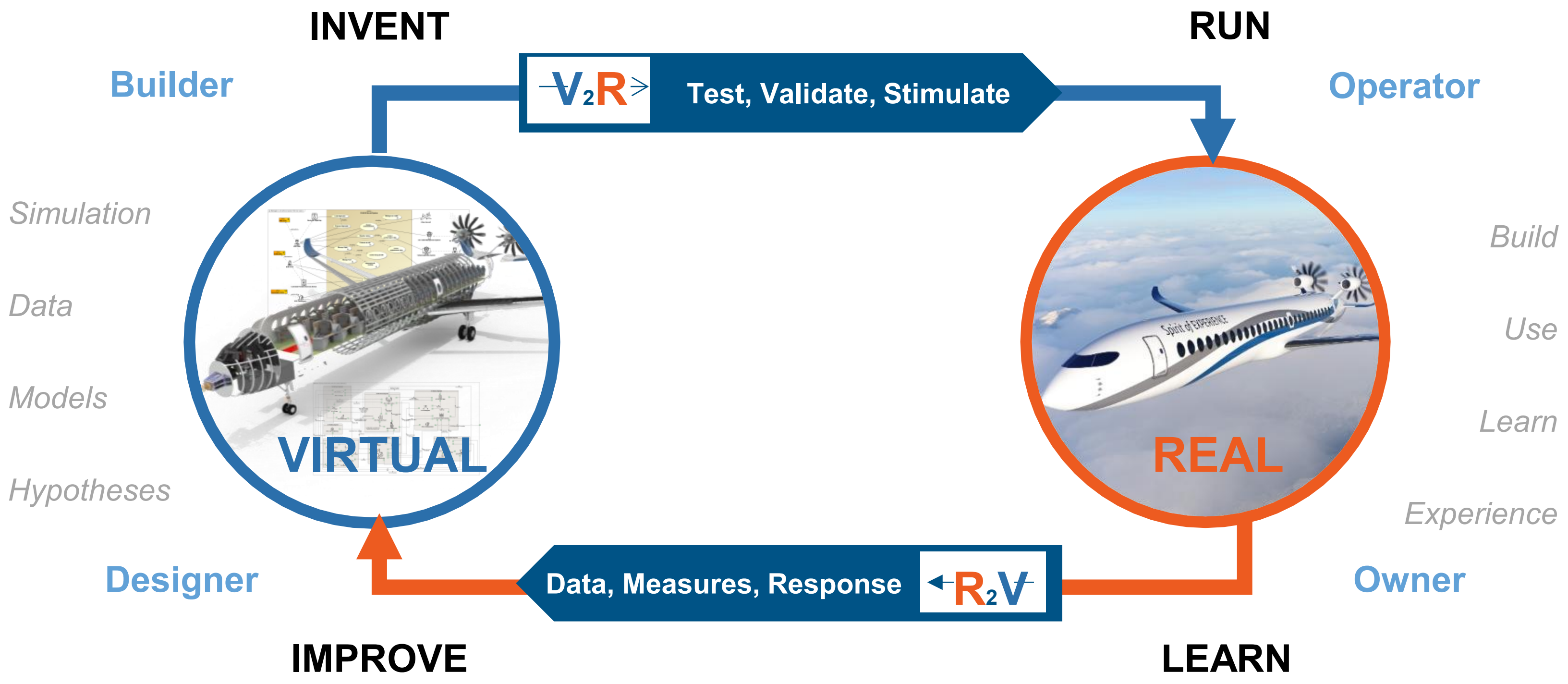
…

…and new "market shakers"

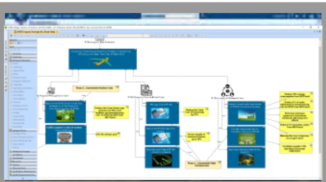
…

What Is Virtual Twin?

A Virtual + Real scientific representation of a Product, Service, Asset or Organization integrating Knowledge and Know-How

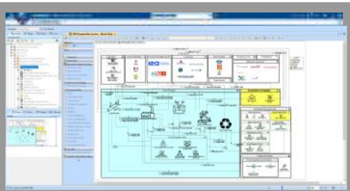


Create Virtual Twin Experience along the System Lifecycle



Enterprise Twin

- Transformation Strategy
- Process referential & Applicative Programs
- Organization & Resources



System of Systems, System Product Twins

- Mission Engineering
- Systems Engineering
- Product Design

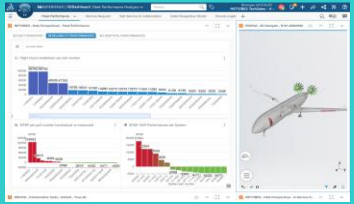
Industrial Network Twin

- Design for production
- Supply chain Planning
- First Article

Manufacturing Twin

- Design for Manufacturing
- Supply Chain Planning
- Manufacturing Execution

Support & Service Twin



- Service Design
- Service Execution
- Logistic Support for Operations

AS NEEDED

CONCEPTUAL OPERATIONS & STUDIES

AS SPECIFIED

PRELIMINARY DESIGN & JOINT DEFINITION

AS DESIGNED

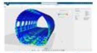
DETAILED DESIGN

AS PLANNED

AS BUILT

MANUFACTURING & ASSEMBLY

AS CERTIFIED



GROUND & FLIGHT TESTS

AS MAINTAINED

IN-SERVICES OPERATORS & SUPPORT

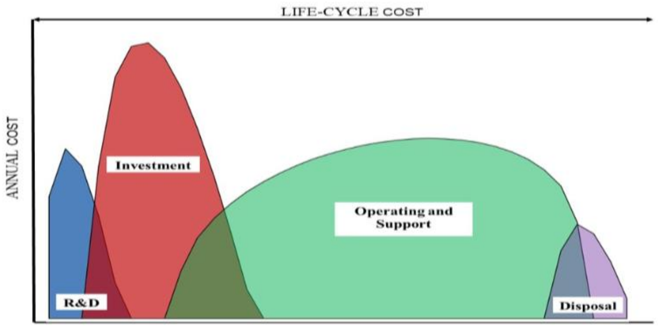
Sustainment and Support Readiness Challenges

High Cost related to Maintenance, Repair, and Overhaul (MRO)

"Sustainment cost constitutes 70% of a weapon system's total ownership cost."

Source: U.S. Government Accountability Office (GAO)

Illustrative Annual Cost x Lifecycle Cost



Source: US DoD Cost Assessment and Program Evaluation

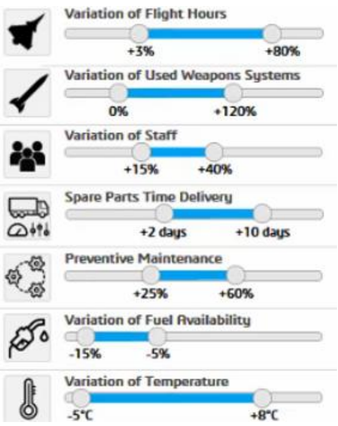
Modeling & Simulating required to predict and optimize Operational Availability

System of Systems Interdependencies

- Coordinating across **multiple nations, industrial stakeholders and systems**

Missions Variability & Unpredictability

- Mission **intensities**
- Multiple combat systems **configuration**
- **Environmental** conditions
- Equipment **failures**



Availability of decision-support tools for "non-MBSE Specialist" during MRO

Use Case: Rafale Aircraft Fleet Sustainment and Support System

Goal: Achieve high level of Operational Availability

- **Key Stakeholders**
  - **Air Force**
  - **Defense Contractors** (delivering "full in service support" fixed price Program)
  - **Support** Entities (Maintenance Crews, Logistics Supply Chain, Spare parts production, …)

- **Questions to solve** (examples)
  - Is the logistics system capable of **supporting high-intensity missions**?
  - Can we **support** for operational exercises with a **given fleet of aircrafts**?
  - What **logistics personnel and means** are required to **optimize support**?
  - What **production and supply flows** are needed for effective aircraft maintenance to support operations?
  - …

A "Virtual + Real" Twin for Support Readiness Framework

VIRTUAL | **REAL**

Step #1. Modular SoS Architectures

Develop SoS Architecture for Aircraft Fleet Operations, Logistics and Maintenance

Step #2. Non-deterministic behaviors

Define Semantics-based Behaviors for SoS Stochastic Simulation

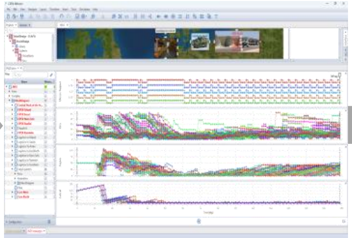
Step #3. Experience "what-if scenarios" for All

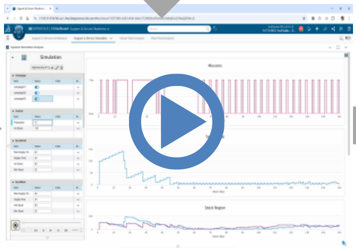
Generate pre-parameterized System of Systems Simulation Scenarios

Step #4. V+R Experience for Decision Making

Monitor Real-world data to optimize support readiness operations

Virtual + Real Comparison





Semantic Graph

Real World Data

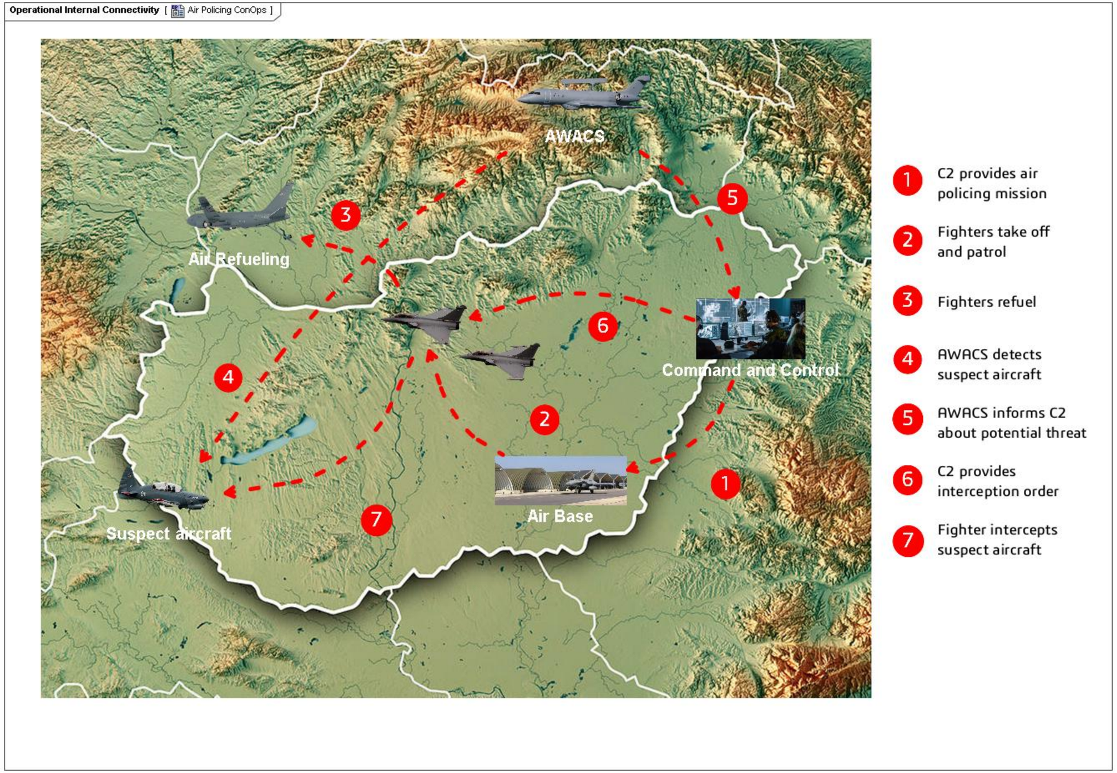
*A framework leveraging **industry standards** for Systems Modeling and Simulation*

Step #1 | Modular System of Systems Architectures

Understand operational usage of aircraft fighter

Air Force operations

Illustration of air policing ConOps

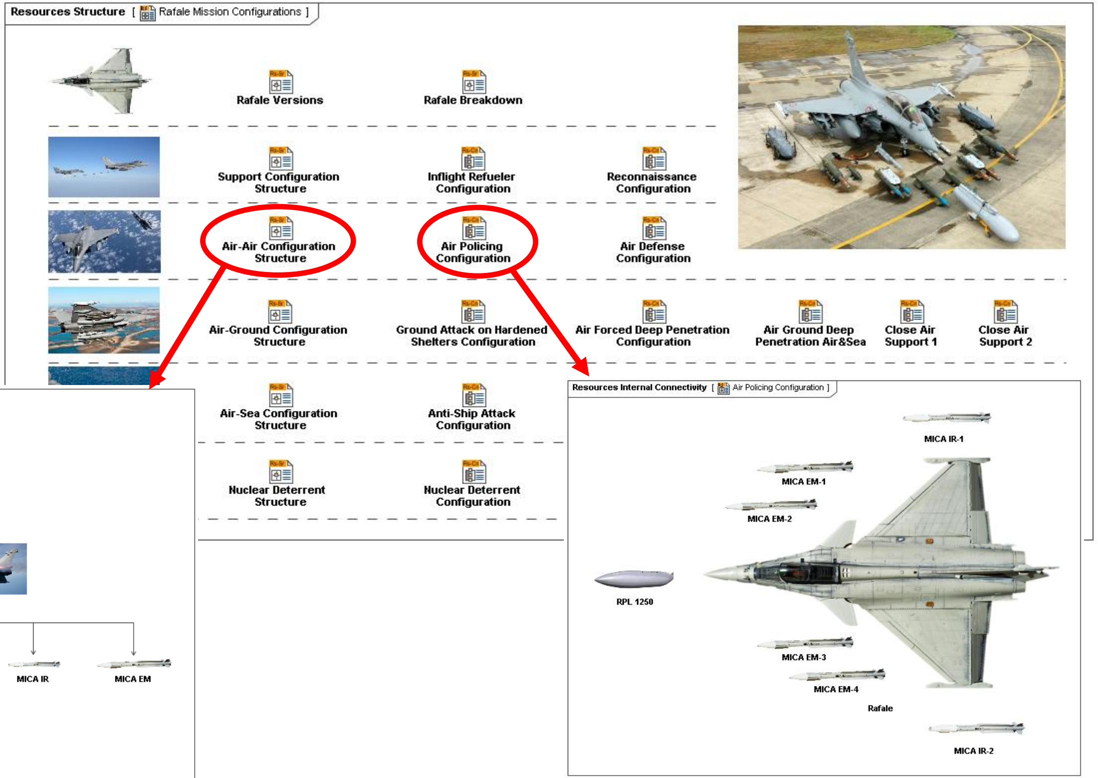


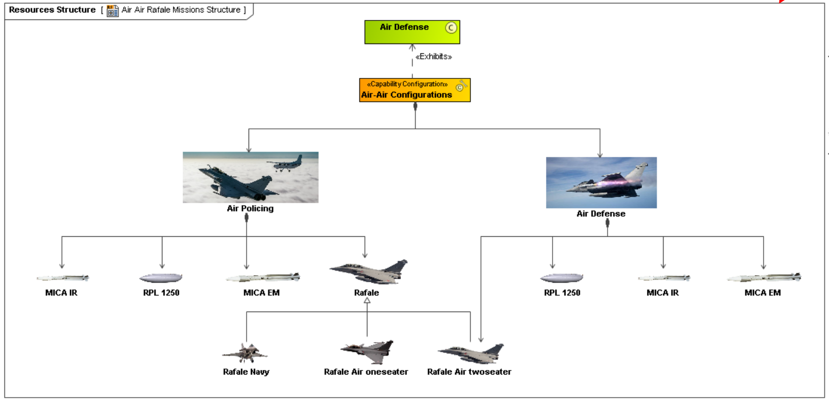
Step #1 | Modular System of Systems Architectures

Understand operational usage of aircraft fighter

Air Force operations

Rafale configurations for operations

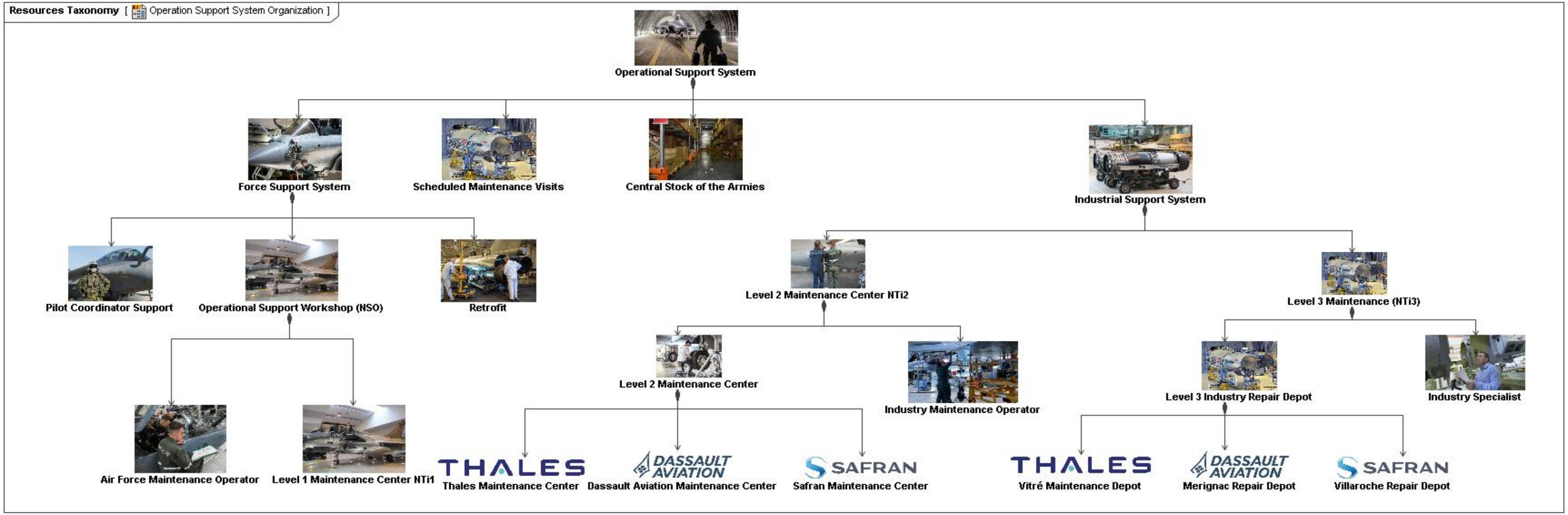




Step #1 | Modular System of Systems Architectures

Understand sustainment of aircraft fighter

Sustainment organization



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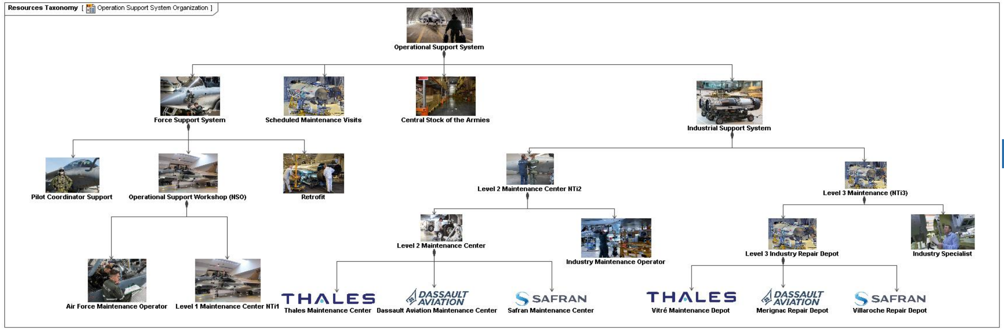
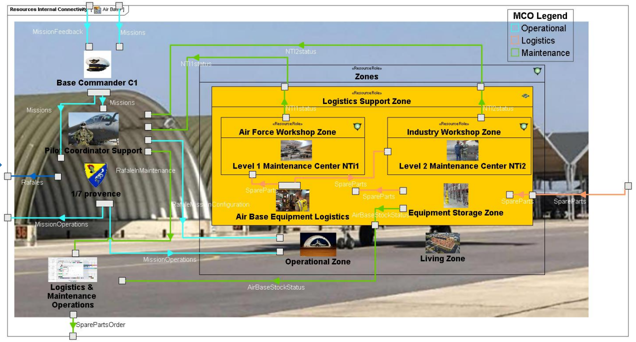


Air base sustainment for operations



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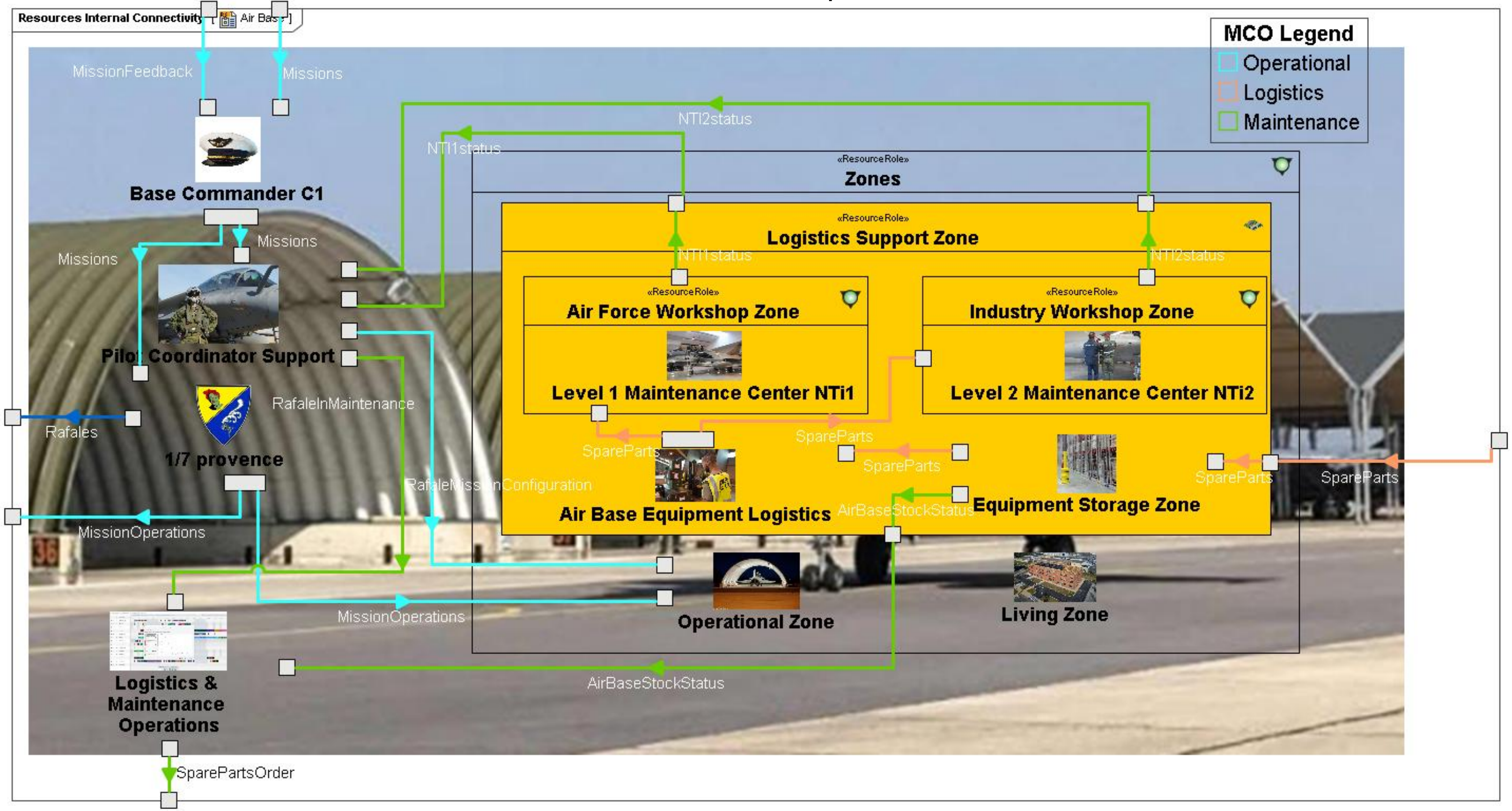
Understand operational usage of aircraft fighter

Air base sustainment for operations



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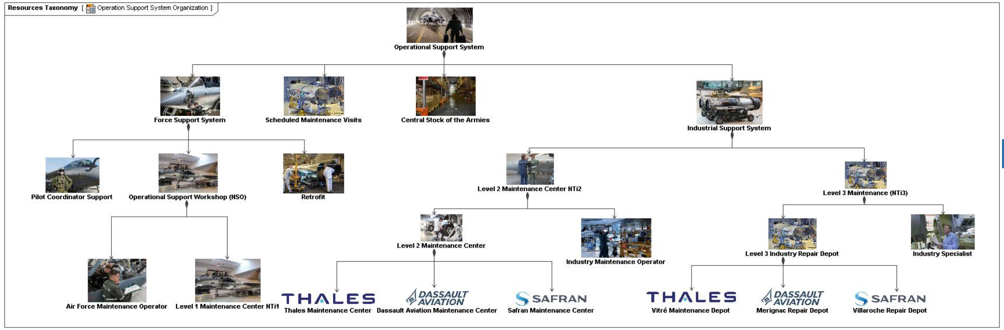
Sustainment organization



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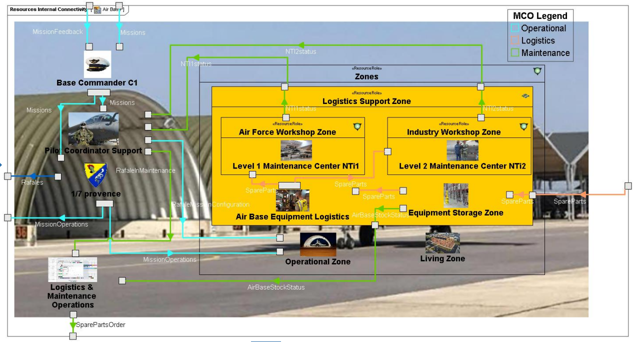
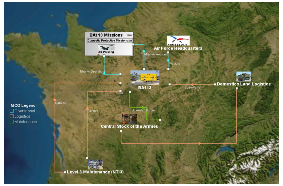


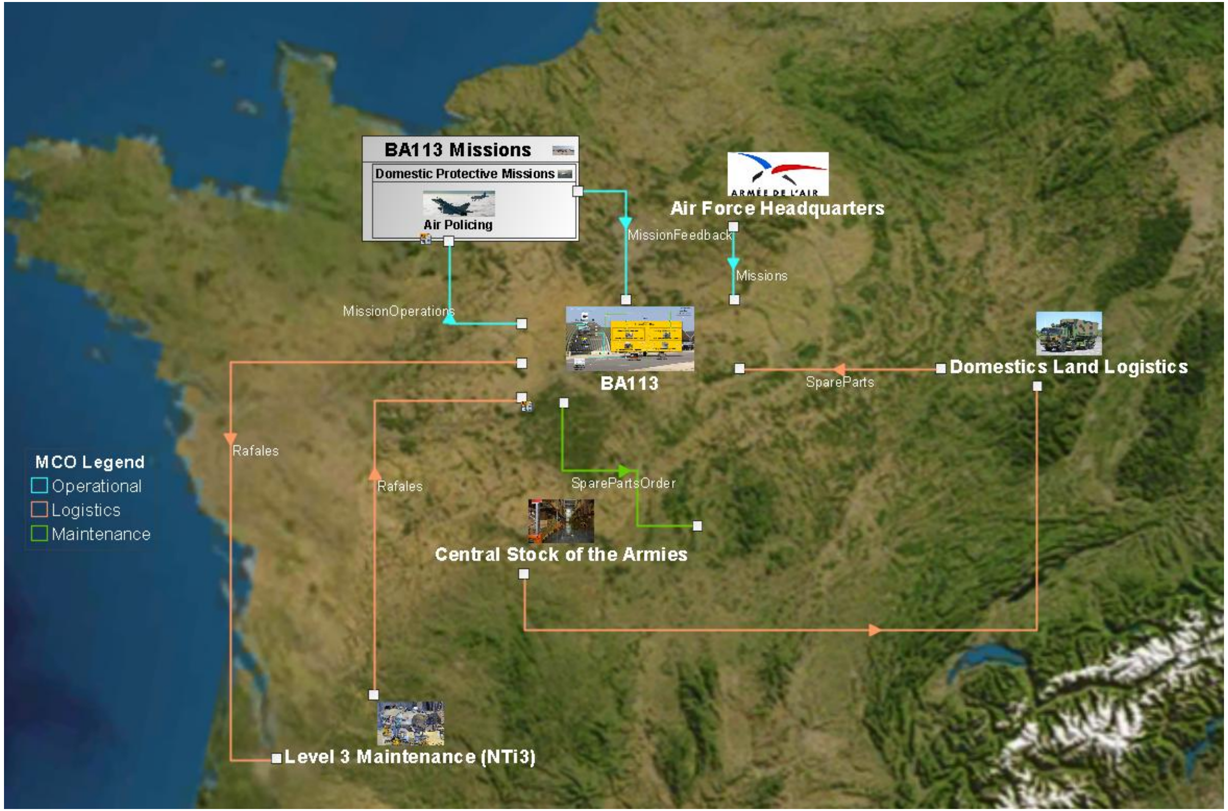
Sustainment architecture for domestic operations



Step #1 | Modular System of Systems Architectures

Understand operational usage of aircraft fighter

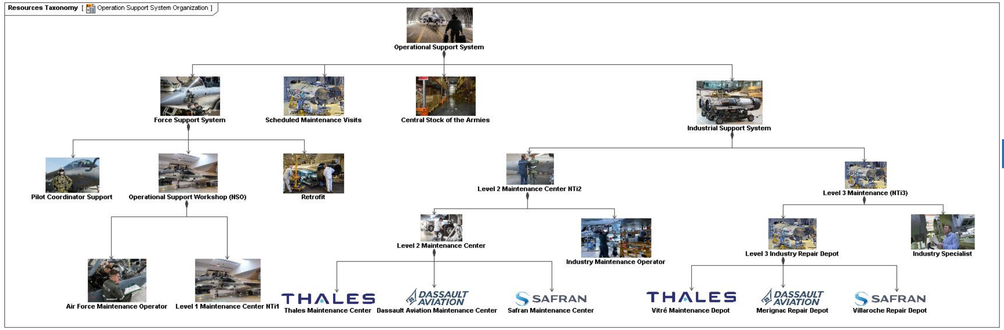
Sustainment architecture for domestic operations: 1 air base, 1 central stock, land logistics



Step #1 | Modular System of Systems Architectures

Understand operational usage of aircraft fighter

Sustainment organization



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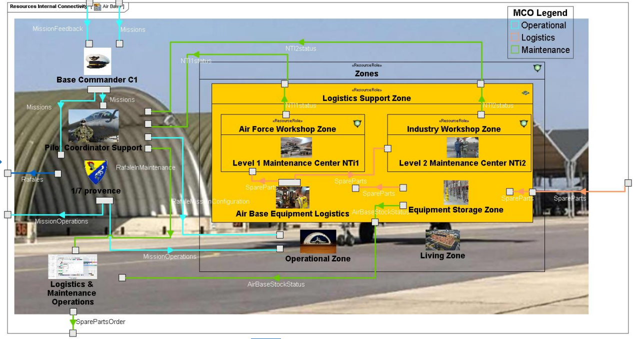
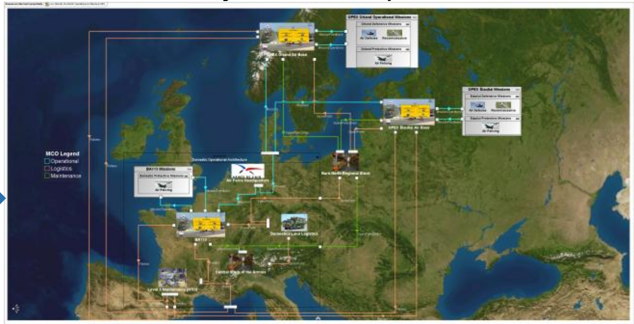
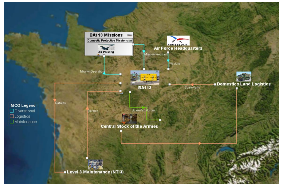


Sustainment architecture for low intensity external operations



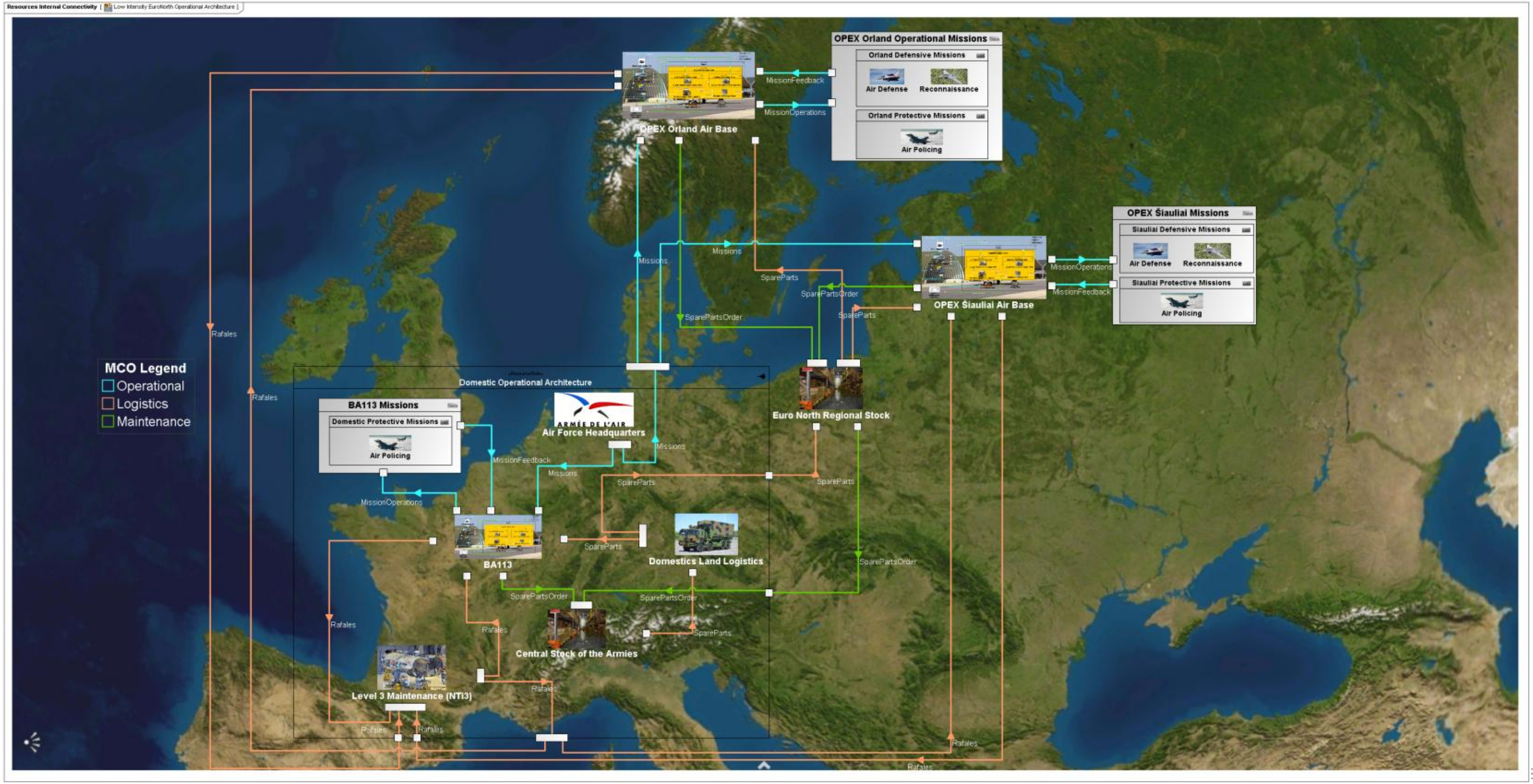
Sustainment architecture for domestic operations



Step #1 | Modular SoS Architectures (1/3)

Understand operational usage of aircraft fighter

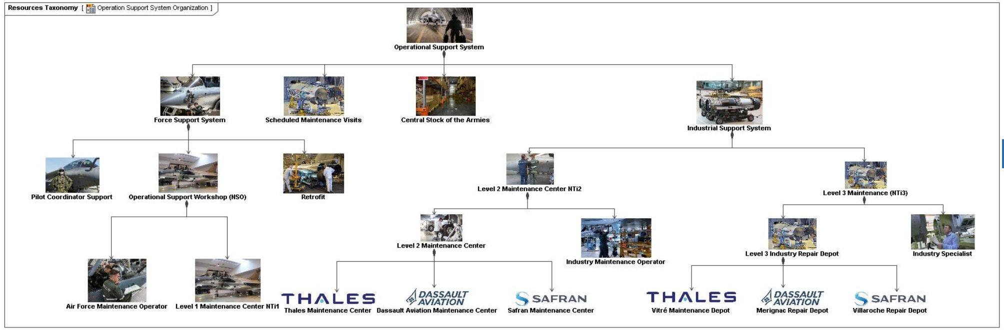
Sustainment architecture for low intensity operations: domestic + 2 external air bases, 2 regional stocks, land logistics



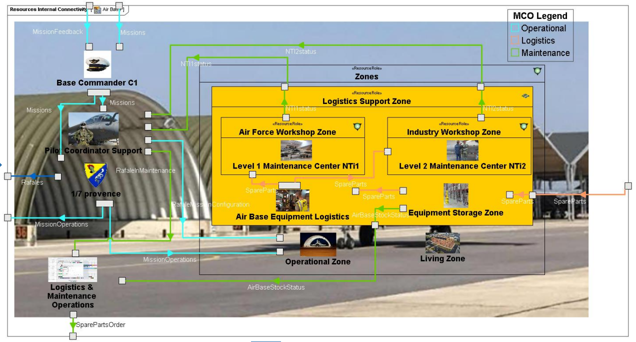
Step #1 | Modular System of Systems Architectures

Understand operational usage of aircraft fighter

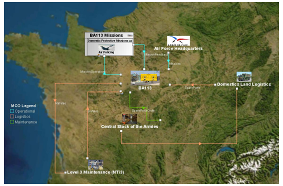
Sustainment organization



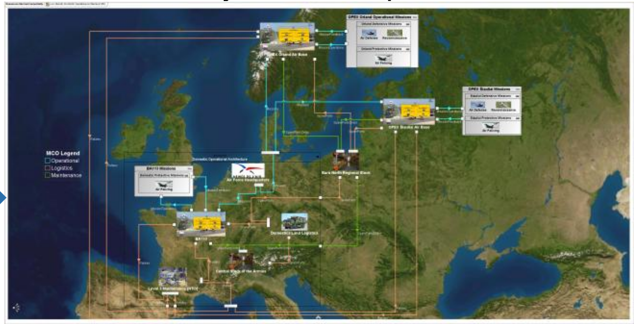
Air base sustainment for operations



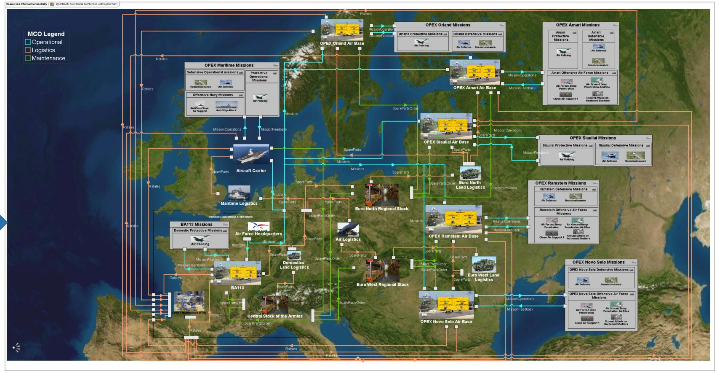
Sustainment architecture for domestic operations



Sustainment architecture for low intensity external operations



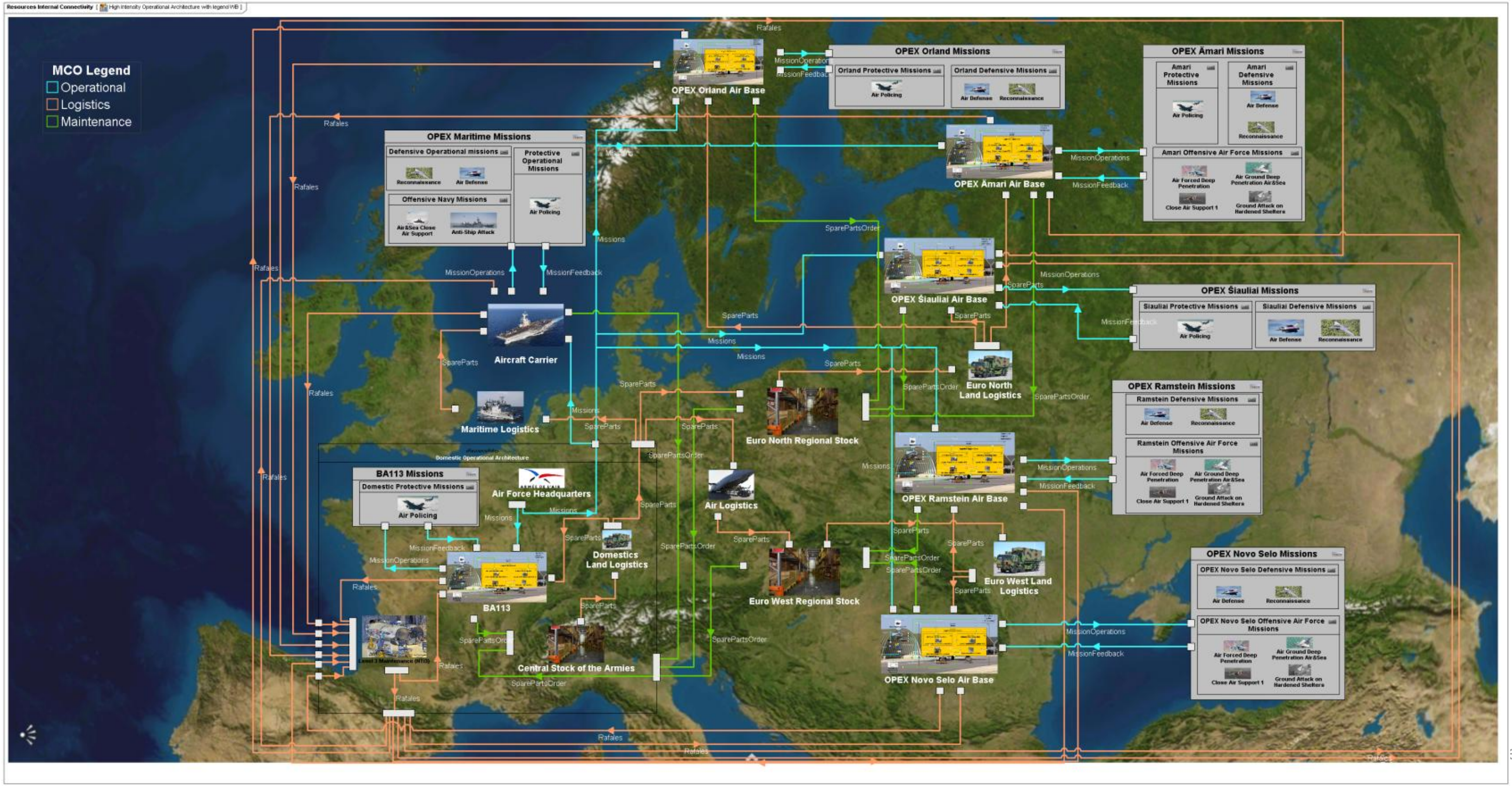
Sustainment architecture for high intensity external operations



Step #1 | Modular System of Systems Architectures

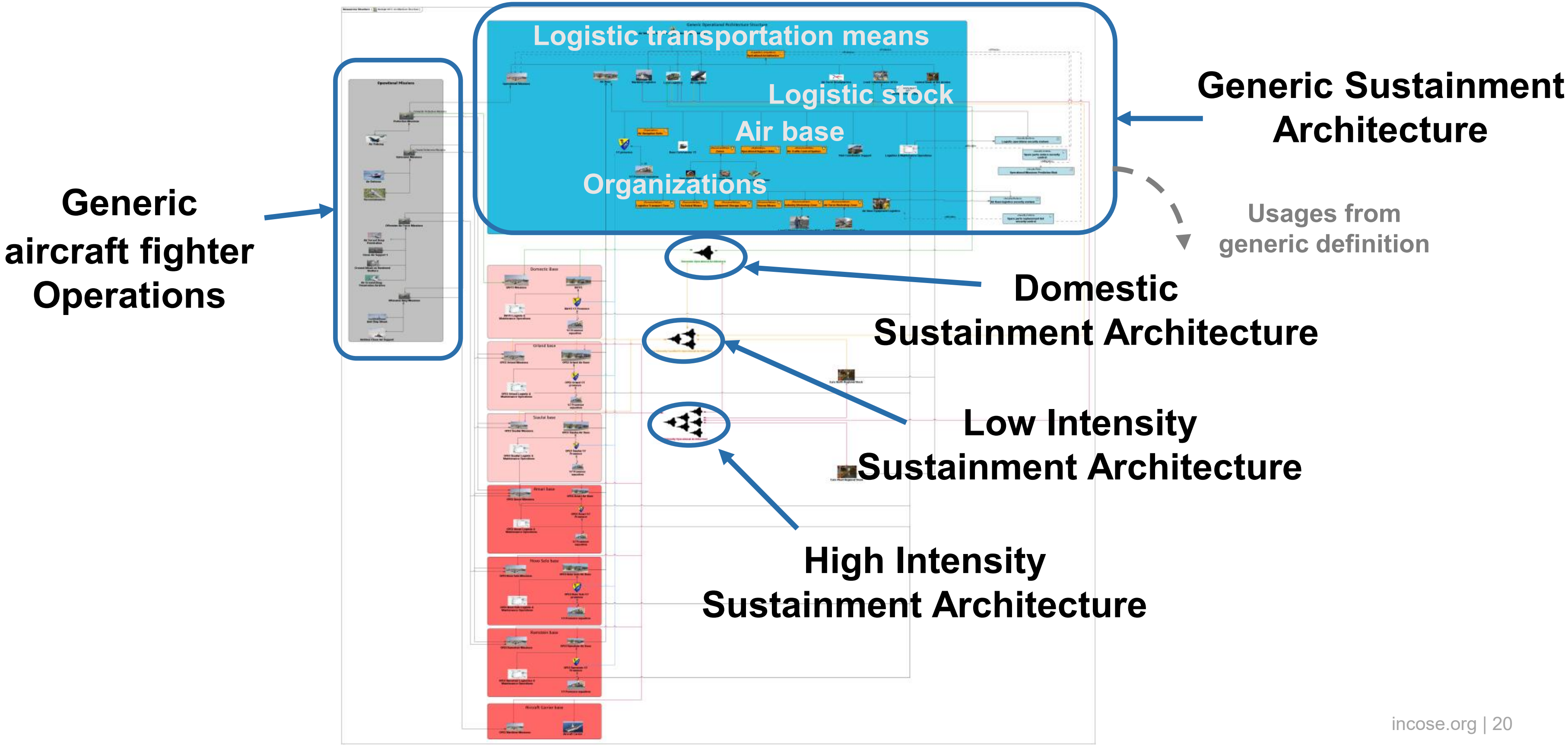
Understand operational usage of aircraft fighter

Sustainment architecture for high intensity operations: low +3 external air bases + aircraft carrier + Land-Air-Sea Logistics



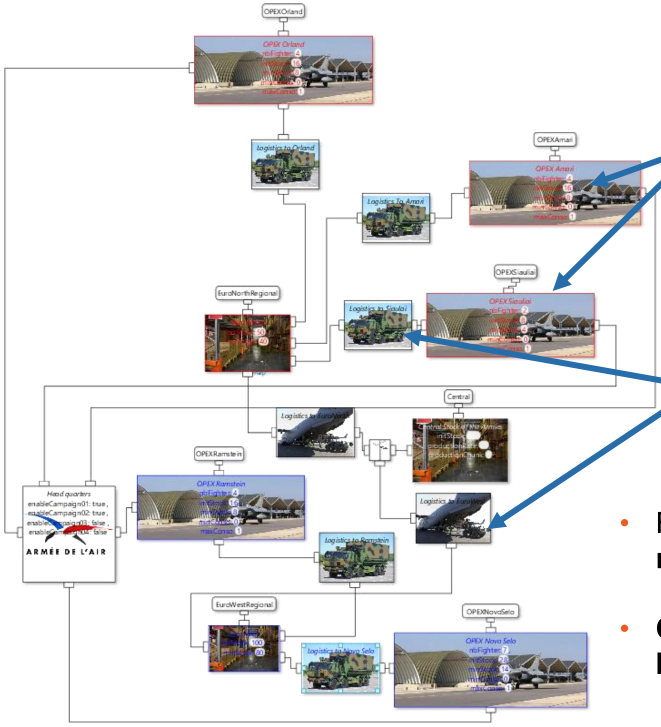
Step #1 | Modular System of Systems Architectures

Behind the scene … a Modular Open Systems Approach (MOSA)



Step #2 | Non-deterministic System Behaviors

System of Systems Architecture



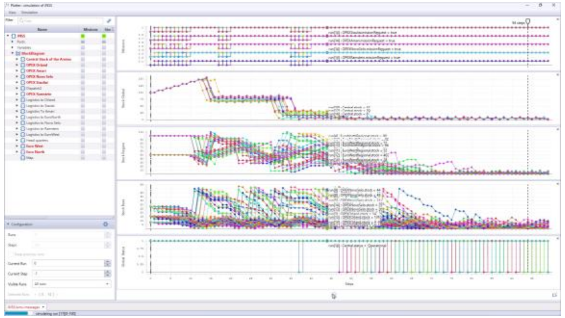
System behavior with executable semantics

```
Initially
    consumption shall be 0
afterwards
    When missionData,
        consumption shall be in range
        [ minConso * nbFighter ,
          maxConso * nbFighter ]
    otherwise
        consumption shall be 0
When baseData.stock is less than minStock ,
    c1.supplyRequest

OutOfOrder : Observe always baseData.stock > 0
```

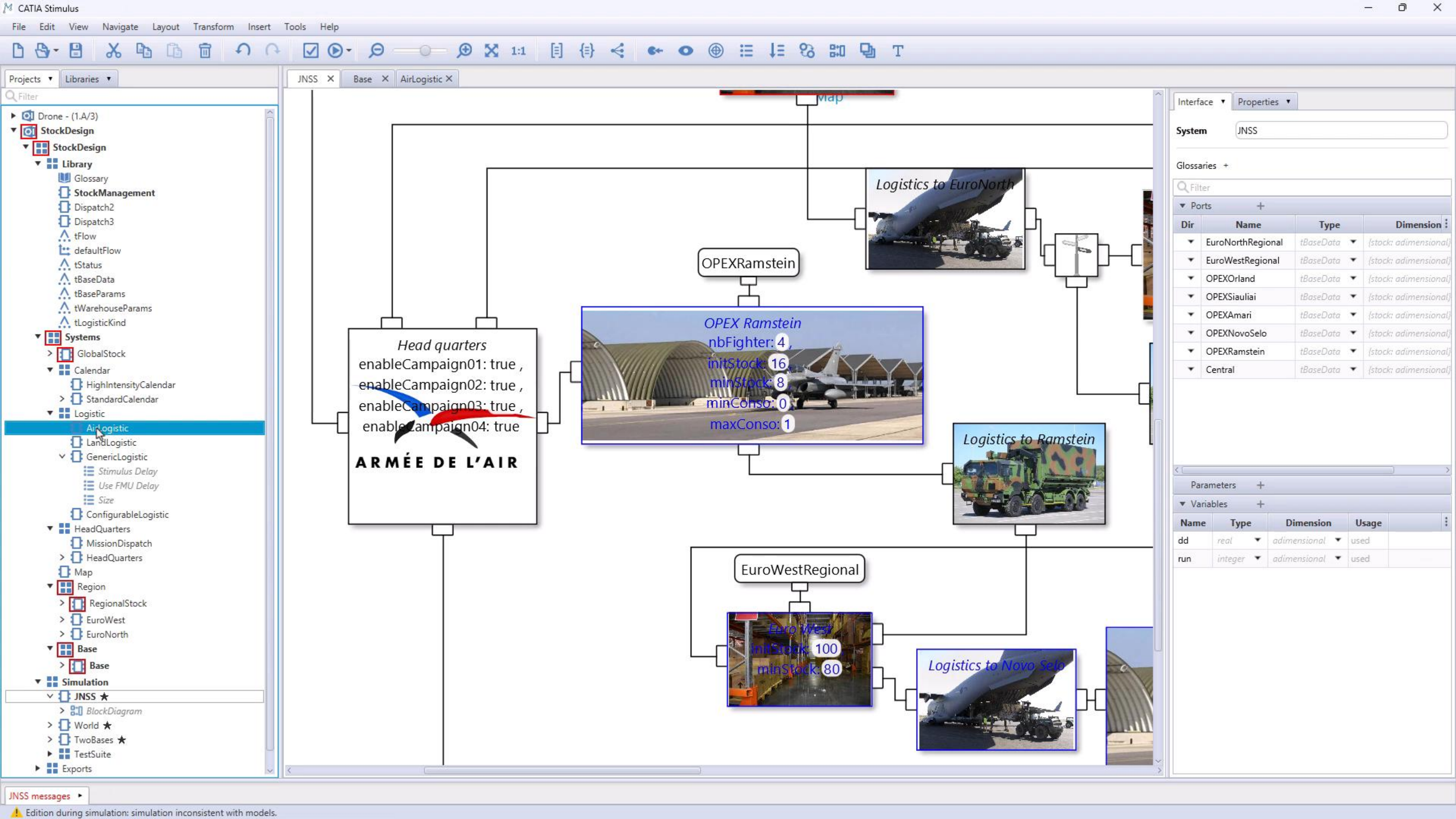
```
Define maxSupply as   (1) 0 if kind = 'None
                      (2) 40 if kind = 'Air
                      (3) 4 if kind = 'Land
                      (4) 10 otherwise

Define duration as    (1) 24 if kind = 'Air
                      (2) 48 if kind = 'Land
                      (3) 48 otherwise
```

- From simple to detailed **behavior in natural language**
- **Constraint-based** and **synchronous language** with **predefined templates**

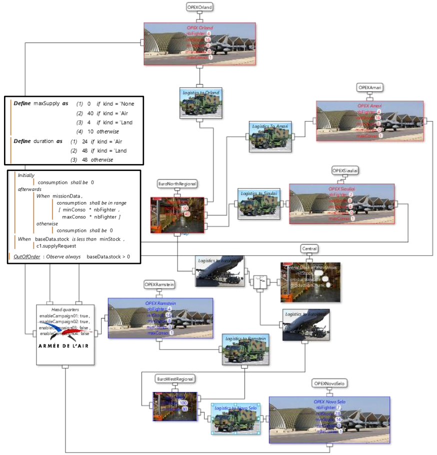
Parametric stochastic simulations



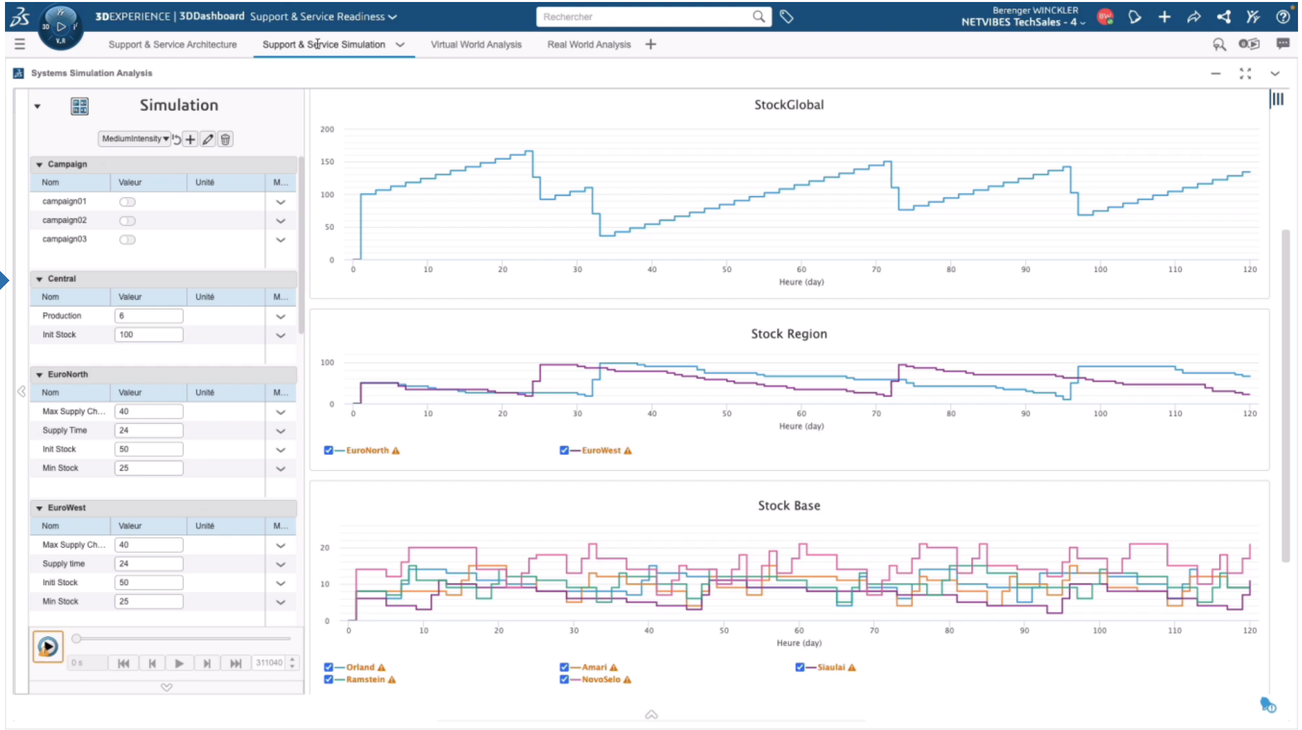
- Assess the **system robustness and resilience** across a large range of **scenarios conditions and uncertainties**


CATIA Stimulus
File Edit View Navigate Layout Transform Insert Tools Help
Projects
Libraries
Filter
Drone - (1.A/3)
StockDesign
StockDesign
Library
Glossary
StockManagement
Dispatch2
Dispatch3
tFlow
defaultFlow
tStatus
tBaseData
tBaseParams
tWarehouseParams
tLogisticKind
Systems
GlobalStock
Calendar
HighIntensityCalendar
StandardCalendar
Logistic
AirLogistic
LandLogistic
GenericLogistic
Stimulus Delay
Use FMU Delay
Size
ConfigurableLogistic
HeadQuarters
MissionDispatch
HeadQuarters
Map
Region
RegionalStock
EuroWest
EuroNorth
Base
Base
Simulation
JNSS ★
BlockDiagram
World ★
TwoBases ★
TestSuite
Exports
JNSS
Base
AirLogistic
Logistics to EuroNorth
OPEXRamstein
Head quarters
enableCampaign01: true ,
enableCampaign02: true ,
enableCampaign03: true ,
enableCampaign04: true
ARMÉE DE L'AIR
OPEX Ramstein
nbFighter: 4 ,
initStock: 16 ,
minStock: 8
minConso: 0 ,
maxConso: 1
Logistics to Ramstein
EuroWestRegional
Euro West
initStock: 100
minStock: 80
Logistics to Novo Selo
Interface
Properties
System
JNSS
Glossaries
Filter
Ports
Dir
Name
Type
Dimension
EuroNorthRegional
EuroWestRegional
OPEXOrland
OPEXSiauliai
OPEXAmari
OPEXNovoSelo
OPEXRamstein
Central
tBaseData
(stock: adimensional)
Parameters
Variables
Name
Type
Dimension
Usage
dd
real
adimensional
used
run
integer
adimensional
used
JNSS messages
Edition during simulation: simulation inconsistent with models.

Step #3 | Experience "what-if scenarios" for all



Parametric stochastic simulation of SoS Architecture

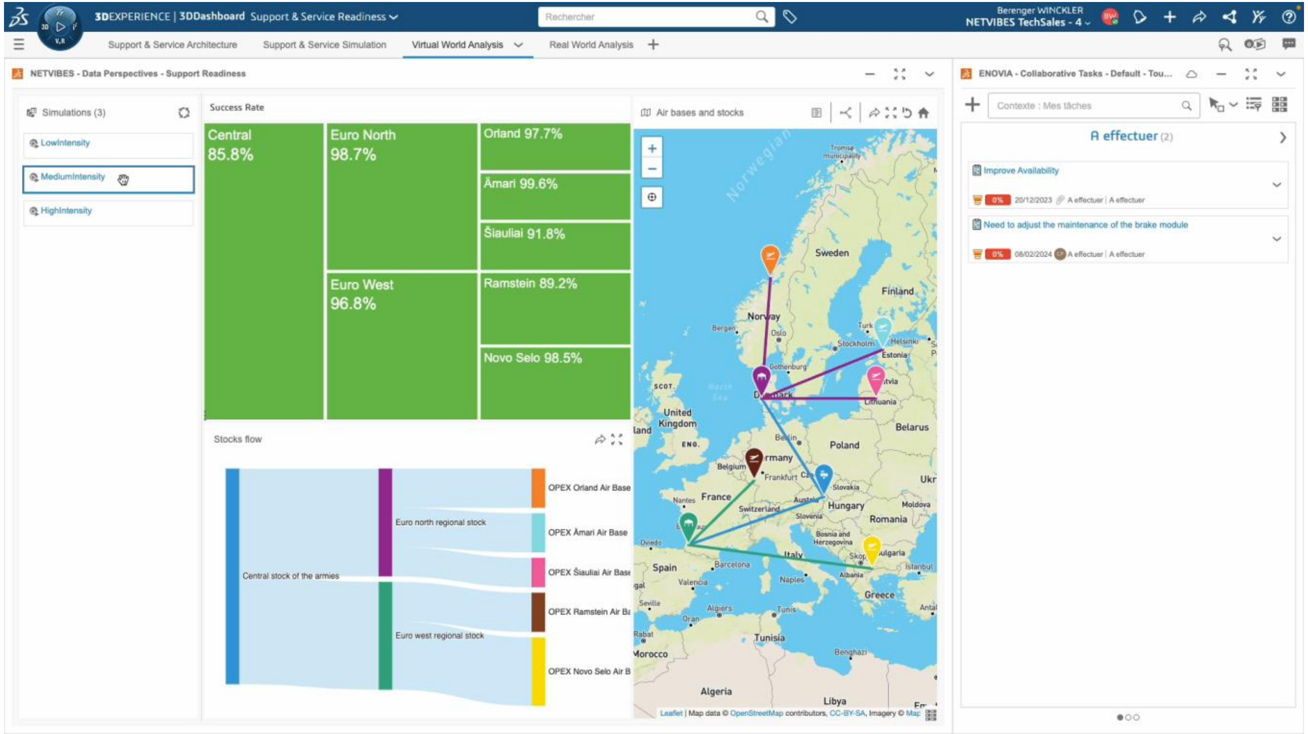


Step #4 | V+R Experience for Decision Making

Reveal engineering insight from the virtual world

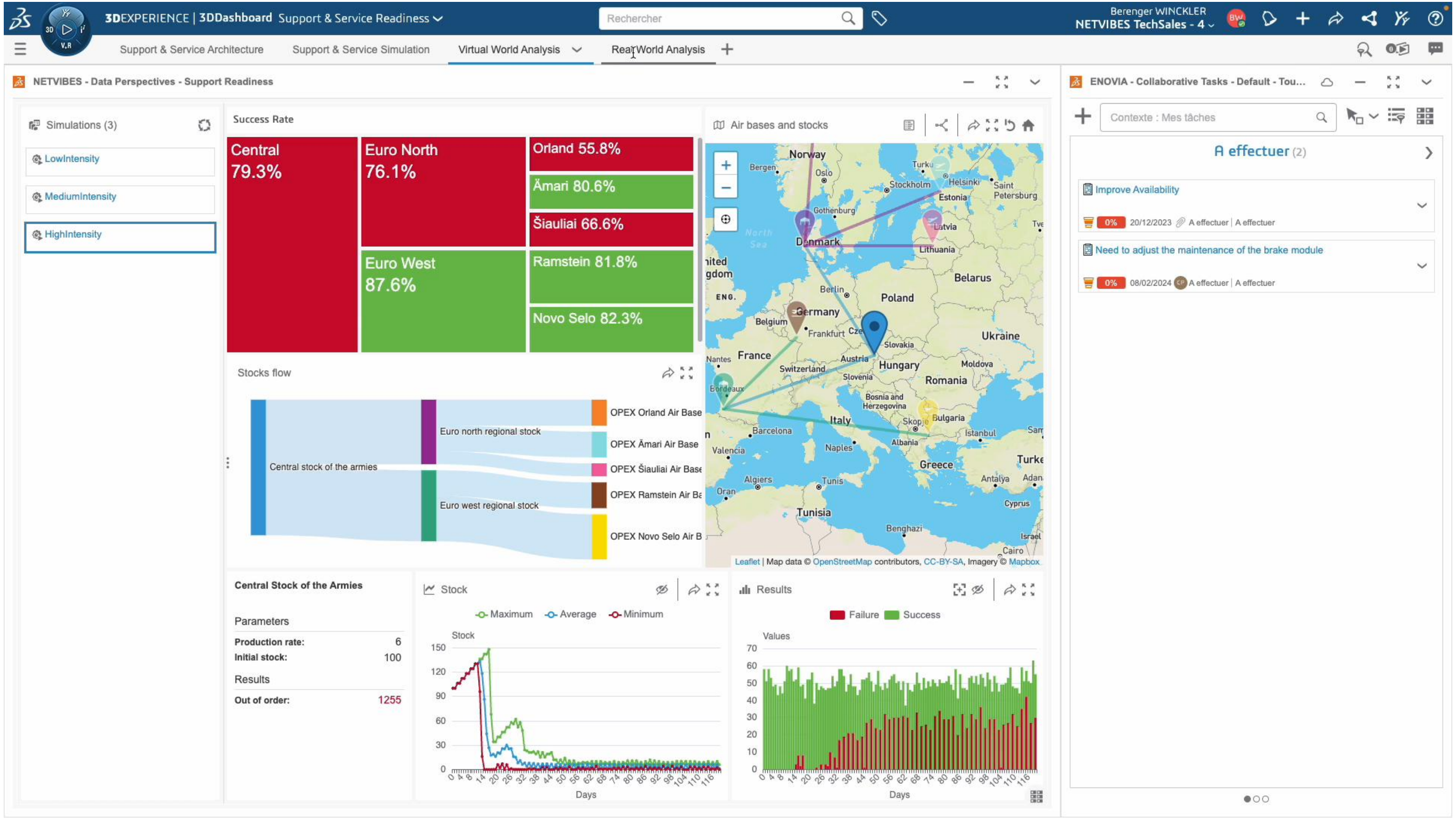
Parametric stochastic simulations

Simulation results analysis based on SoS Architecture



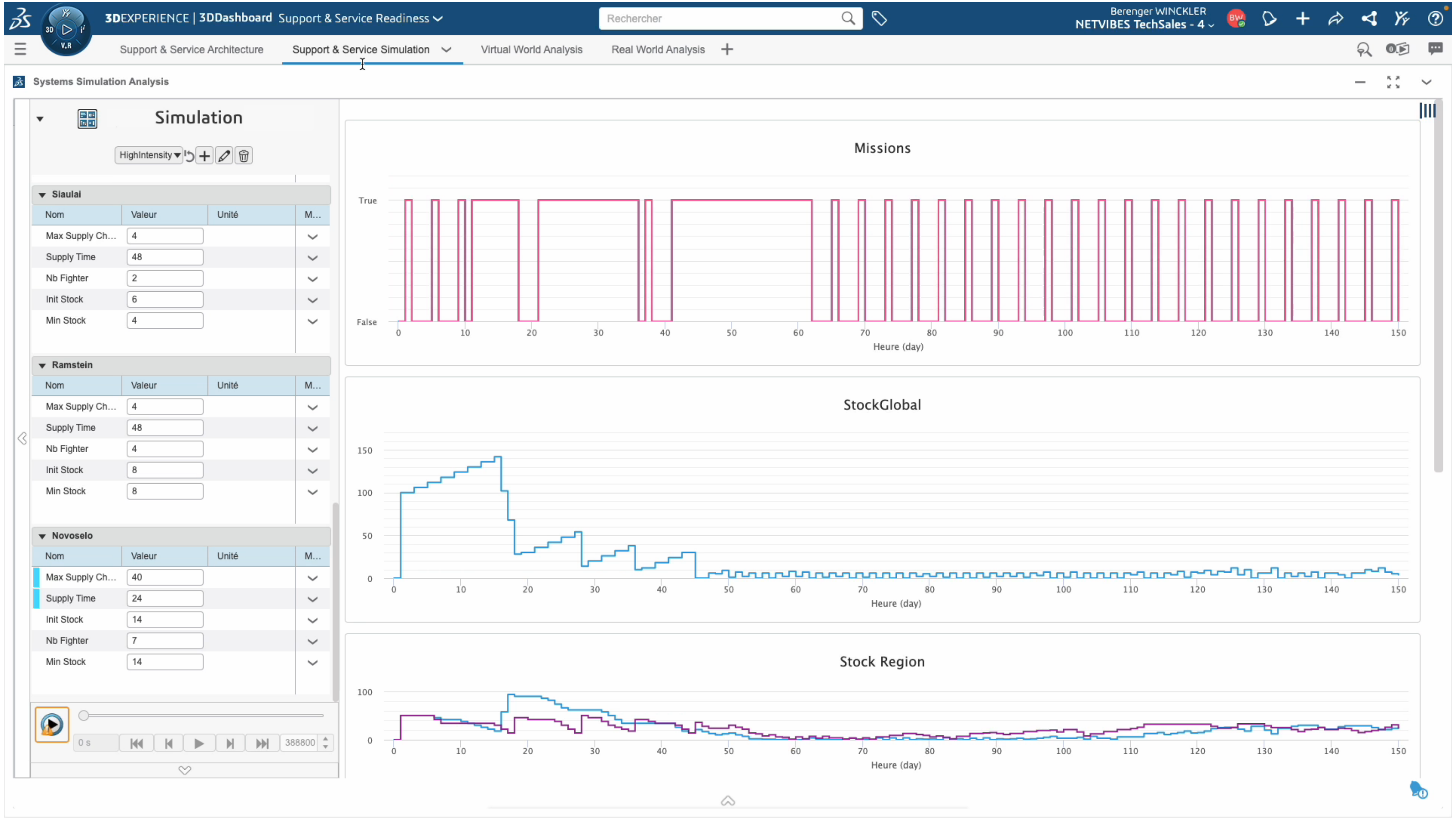
Step #4 | V+R Experience for Decision Making

Enable virtual to real comparison to optimize the system leveraging SoS Architecture



Step #4 | V+R Experience for Decision Making

Understand the real world with new hypothesis in the virtual world



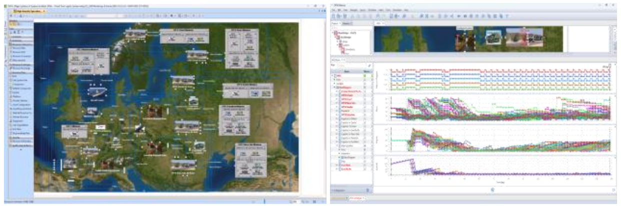
Virtual + Real Twin Experience for Support Readiness

Implementation Framework Overview

Virtual World

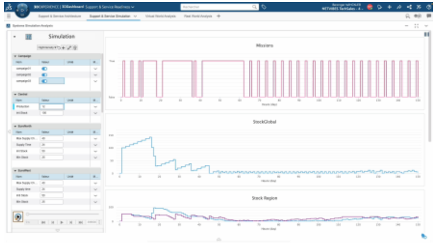
Model-Based Systems Engineering approach (Modeling & Simulation)

UAF OMG UNIFIED ARCHITECTURE FRAMEWORK



CATIA | Magic

STIMULUS



CATIA

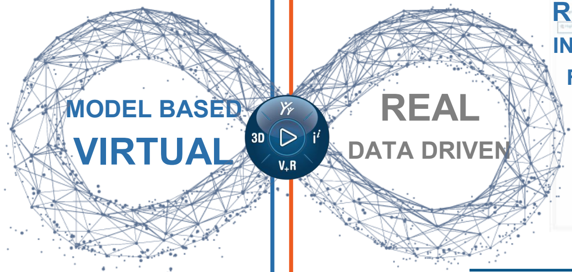
Systems Simulation Design

ssp

fmi

INDUSTRIALISATION

FEEDBACK LOOP



Real World

Data Science Experiences

Experience

NETVIBES

REVEAL ENGINEERING INFORMATION COMING FROM THE VIRTUAL WORLD

MAKE THE DATA ACTIONABLE DETECTING PROBLEM COMING FROM THE REAL WORLD

V + R COMPARISON TO IMPROVE THE SYSTEM

Elevate

- Knowledge Graph
- Ontology
- Intelligence

Ingest

- Simulation
- PLM
- IoT
- ERP, CRM,…

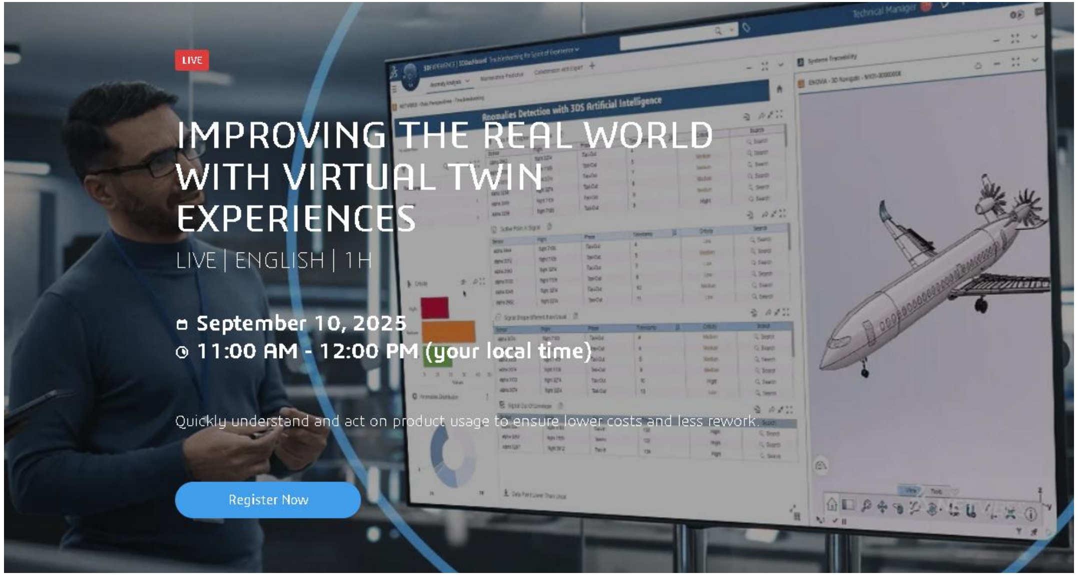
VIRTUAL WORLD DATA | REAL WORLD DATA

Conclusion | Transforming "VUCA"

Volatility, Uncertainty, Complexity, Ambiguity → Vision, Understanding, Clarity, Agility

- **Define Architecture as the Authoritative Source of Truth**
  - **Align stakeholders** with a consistent "blueprint" on mission needs and operational constrains
  - Enrich architecture with simulation to **explore and assess sustainment strategies**
- **Bridge Virtual and Real to improve Mission Readiness**
  - **Engineers** (system architects, designers…) benefit from real-world context feedback to validate assumptions and improve performance & maintainability
  - **Operators** (headquarters, squadrons, logistic coordinators…) can make informed decisions by simulating 'what-if' scenarios in a virtual twin environment, enabling them to adapt to evolving operational conditions and maximize aircraft fleet availability

Join September 10 Webinar!



- **Explore "what-if" scenarios for optimized design and performance**
- **Enhances operational efficiency and decision-making, with practical industry applications**

https://events.3ds.com/improving-real-world-virtual-twin-experiences

Meet Dassault Systemes Team at IS2025!

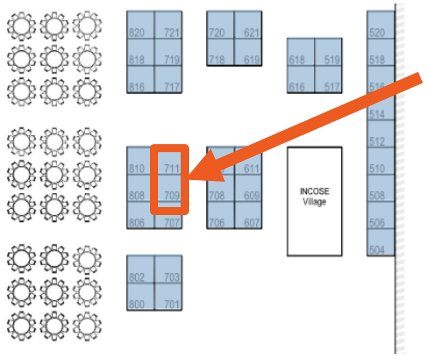


Exhibit Hall

Booth 709-711

QR code with Session Details

Track	Day	Start	End	Room	Type	Dassault Systemes's Sessions at IS25
1.1.1	Mon	10:00	10:40	Hall 3	Presentation	Case Studies for Querying the Model - **SysML V2**
1.7.1	Mon	11:00	11:20	201	Presentation	Exploring the Next Frontier: **SysML V2**
1.1.3	Mon	11:30	12:10	Hall 3	Paper 185	Exploring the Use of **SysMLv2** for Solution Architecture Development with the MagicGrid Framework
1.2.3	Mon	11:30	12:10	214	Paper 320	Towards a **Digital Engineering Ontology** to Support Information Exchange
2.4.1	Mon	13:30	14:10	215	Paper 340	**Systems Engineering with Attitude**
2.4.2	Mon	14:15	14:55	215	Presentation	Taming the Beast: Best Practices of Extending **SysML V2**
4.7.1	Tue	10:00	10:20	201	Presentation	**Digital Engineering and MBSE with Virtual Twins**: Streamlining Robotic Arm Design and Deployment
5.3.1	Tue	13:30	13:55	213	Paper 26	**Systematic Risk Analysis**: FMEA and FTA Approaches for Multi-Level System Architectures
5.3.2	Tue	14:00	14:25	213	Paper 270	SysML4Sec – Methodology for **Security modeling** in the context of large-scale product development with multiple design levels
5.3.3	Tue	14:30	14:55	213	Paper 147	A System-of-Systems Modeling, Simulation and Data Analytics Framework for Resilient **Sustainment and Support Readiness** Strategies
6.5.3	Tue	16:30	16:55	208	Paper 128	Model-Based Systems Engineering **for Industrial Systems**
7.2.1	Wed	10:00	10:40	214	Paper 361	A Transformative Process for **Model-Based Design Reviews**
8.1	Wed	13:30	14:55	Hall 3	Panel	Bridging the Divide: **Linking Architectural Specification and Verification** by System Simulation
9.1	Wed	15:30	16:55	Hall 3	Panel	Cost Impacts of **Generative AI** in Systems Engineering Processes
9.5.2	Wed	16:00	16:25	208	Paper 30	Navigating Innovation: **MBSE Adoption** at Turkish Aerospace Industries
9.5.3	Wed	16:30	16:55	208	Presentation	**Configuration Management** Challenges in Multi-Team Collaboration Using Linked Models
10.2.1	Thu	10:30	11:10	214	Paper 164	**Enterprise Transformation** Planning with UAF
11.5.3	Thu	14:00	14:25	208	Paper 108	Integration of MBSE and **Agile** Development by Seamlessly Creating **Test Plans from Model Simulations in SDV Development**

35th Annual **INCOSE** international symposium

hybrid event

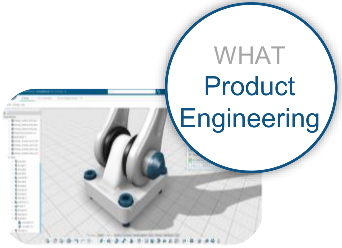
Ottawa, Canada

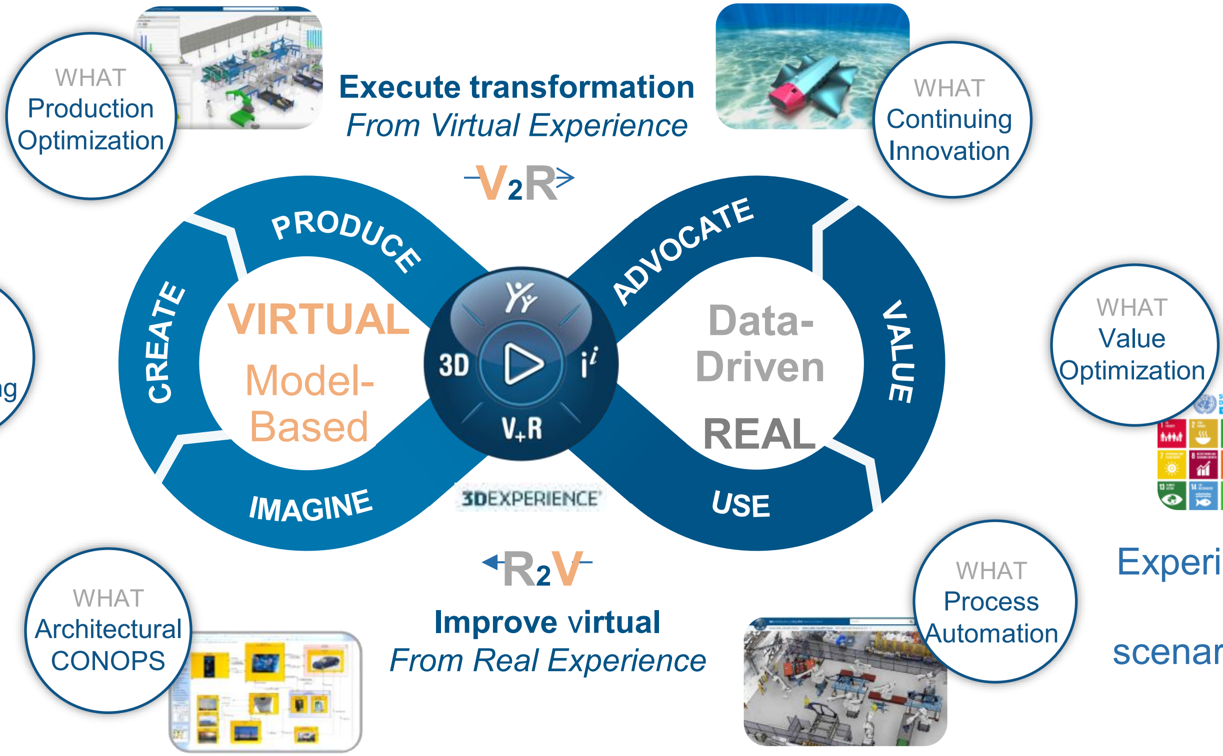
July 26 - 31, 2025

Create the "Virtual Twin Experience"

Collaborative environment connecting the entire system life cycle with a continuous digital thread

A collaborative environment connecting virtual with real





Experiencing real-life, what-if scenarios or "what could be"

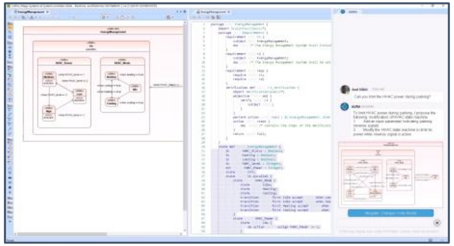
Recommendations for Future Work

Evaluate the framework with cross-industry Application, for example:

- Commercial aircraft: Enable feedback loops between operations and design
- Industrial equipment / Smart factories: Optimize production line readiness
- Energy plants: Improve resilience in grid infrastructure
- Public transportation: Simulate and optimize assets city-wide using traffic and usage data

Leverage AI, Knowledge Representation & Semantic Modeling

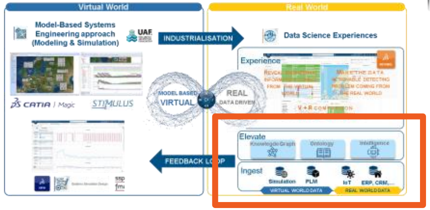
- Apply predictive maintenance using machine learning trained on real-world data
- Integrate KGs with large language models (LLMs) for AI-assisted model querying and simulation, leveraging context and semantics to reduce hallucination



Organizational and Workforce Development

- Address skill gaps in modeling, sustainment, and domain-specific MRO knowledge
- Develop tailored education, training programs and cultural/process transformation

Step #4 – Data Intelligence (Technical Details)



- **Create Semantic with Ontologies & Knowledge Graphs (KG)**
  - Use of ontologies to integrate, unify, and represent data from diverse sources
  - SoS UAF Architecture translated into interactive KG, enabling semantic-rich knowledge graphs

- **Ingest, analyze and contextualize Data**
  - Machine Learning models analyze time-series data for event detection and anomaly discovery
  - Aggregates multi-source heterogeneous data, including structured and unstructured data such as repair records from the maintenance system, systems models and simulation results

- **Create and distribute Data Science Experiences**
  - Low-code platforms enabling web-based custom dashboards for sustainment, support and predictive maintenance
  - Supports operational decision-making and KPI tracking for all stakeholders involved in Support & Operation activities