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

Model-based System Verification Applied to Spanish Navy's S80 Class Submarine Sustainment Case Study

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Navantia accenture SIEMENS

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Outline

- Background
- Introduction
- Methodology
- Conclusion

S81 Isaac Peral

Spanish Navy Challenges

- Current Needs
- S80 TLS Program
- SoS Challenges

The Spanish Navy Needs

Sustainment Admiralty Vision

III. **La eficacia operativa y la eficiencia en la gestión como objetivos permanentes del arsenal**. En tres vertientes diferenciadas (3E):

- **Operational availability of units and its systems** ivel posible de disponibilidad operativa de las unidades y de sus sistemas, equipos y componentes. La calidad de las acciones de sostenimiento y el menor consumo del recurso "tiempo", en mantenimiento o para la restauración de una capacidad, darán una buena medida de esta.

- **Cost efficiency** , de forma que se maximice el rendimiento de la disponibilidad presupuestaria para cubrir las necesidades de las unidades a sostener y del propio arsenal. El rendimiento obtenido de los créditos asignados será el factor más relevante para su medida.

- **Environmentally friendly** objeto de lograr una óptima gestión de residuos (conforme a los estándares más exigentes) y aumentar la eficiencia energética, incluso mediante la autogeneración de energía no contaminante, para tratar de alcanzar al objetivo de una huella cero de CO2. Los factores "contaminación" y "mínimo gasto energético" son los de mayor relevancia.

VII. El conocimiento preciso en todo momento de **current status of units** y **status prediction** permita adelantarse a sus necesidades de sostenimiento mediante la ' **prescription of solutions.**

The S80 TLS Program Organization

Cross-Enterprise Stakeholders

OTACV S80

TLS Program Office

ISDEFE

ILS Engineering

- ILS Engineering

Spanish Navy

Operational Expertise

- Operational analysis

Navantia

Technical Authority

- Design changes and evaluation
- Configuration management

S80 TLS Program

Roadmap

Continuous relationship with Suppliers for the Submarine Life Cycle

TLS Preparation — **2021**

TLS Support Kick Off — **Delivery** — **2023**

2030

Transition Phase

- TLS Team Conformation ACV
- Elaboration of plans (Maint./Supply/Engineer/Mngmt.)
- Elaboration of Agreements with OEM
- Data Management System
- Infrastructure Setting Up
- Establishment of Program KPI's

First TLS Phase: 7,5 years

- Development of the TLS Activity
- Collecting data and updating ILS
- Cost Reduction Objectives
- Monitoring the level of availability and performance

Second TLS Phase: X years

- Transferring risk to the industry
- Payment linked to Availability and program performance
- Transfer requirements to the industry
- Development of the TLS Activity
- Cost Reduction Objectives

ARMADA

ARSENAL DE CARTAGENA
OTACV

SoS Challenges

S80 Program Challenges

SoS Complexity

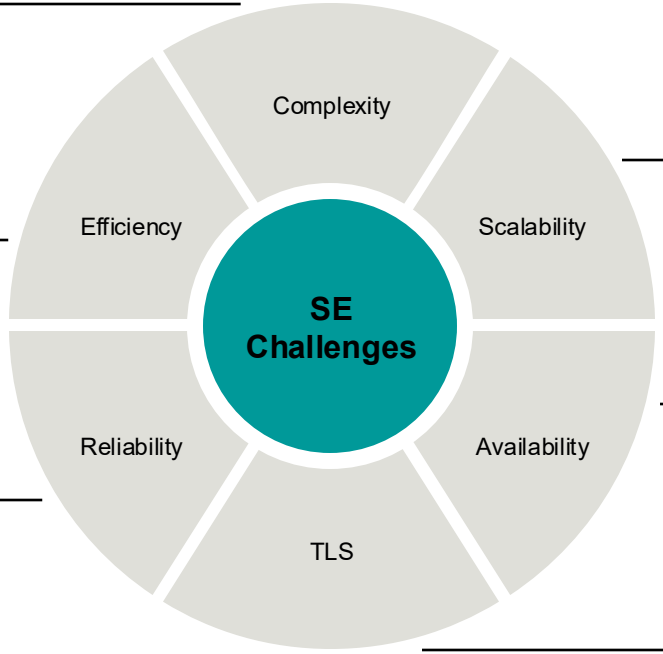
More complex systems integration for navy fleet missions

Operational Efficiency

Through cost evaluation of operation and maintenance

System Reliability

Maintain reliability metrics based on current status of the asset



Scalability

Re-use of existing technology or engineering between project phases and across different projects

Mission Availability

Mission success to be evaluated in terms of capabilities needed

Through Life Support

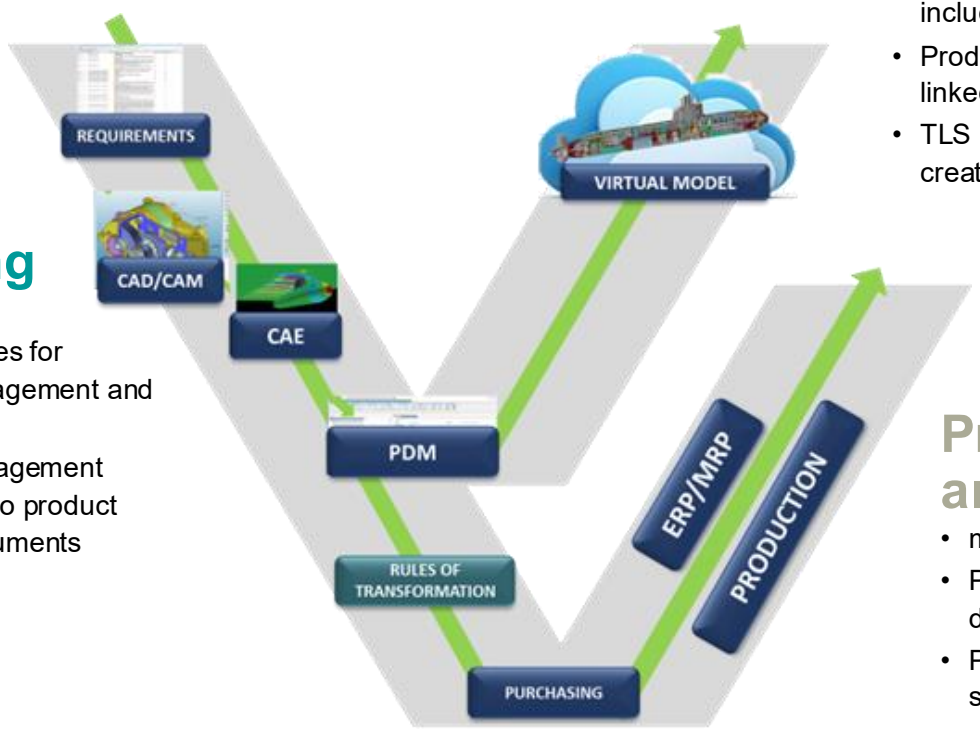
Plan, execute and improve document based preventive TLS

Navantia Systems Engineering Process

Document-based approach is not scalable

Systems Engineering

- Document based
- Stand alone features for requirements management and simulation
- Configuration management integration limited to product design and its documents



Design deliverables:

- Engineering product structure (eBOM) including verification properties
- Product documents and 3D models linked to product structure nodes
- TLS information document based created in stand-alone software

Product realization and verification:

- mBOM created based on rules
- PDM/ERP integration. BOM and documents are pushed to the ERP
- Product realization and verification status recorded in ERP

Acquisition Program SE vs SoS Challenges

S80 Program SoS Challenges

SoS Complexity

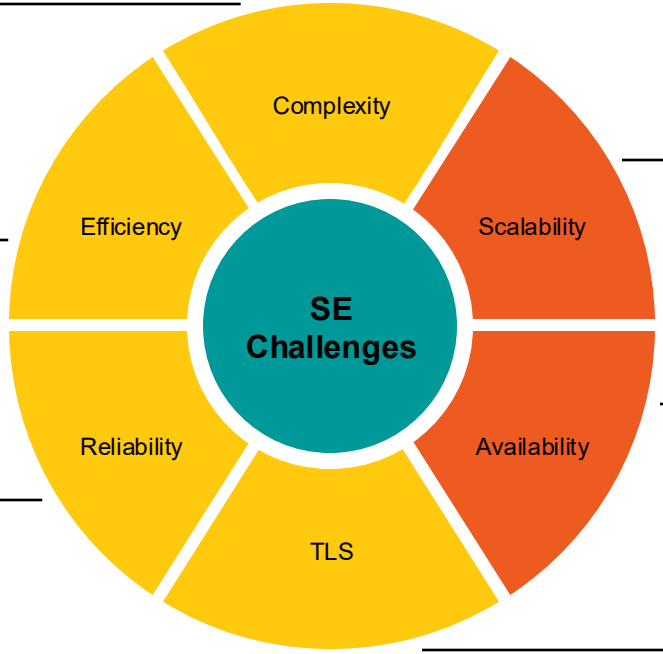
The Sub-system document-based approach requires rebuilding the systems engineering deliverables to be capability oriented

Operational Efficiency

Efficiency was evaluated in a sub-system base, obtain the operational efficiency requires rebuild the analysis

System Reliability

Current status of the asset didn't belong to input parameters of reliability assessment



Scalability

Re-use of items or slight modification of items forces a deep change impact analysis and modifications in deliverables

Mission Availability

Success of the mission is based on performance of different sub-systems, assessing the availability requires re-build the engineering.

Through Life Support

Document-based approach not ready to support lifecycle updates efficiently

Challenge hard to solve

Challenge very hard to solve

TLS Program SE vs SoS Challenges

S80 Program SoS Challenges

SoS Complexity

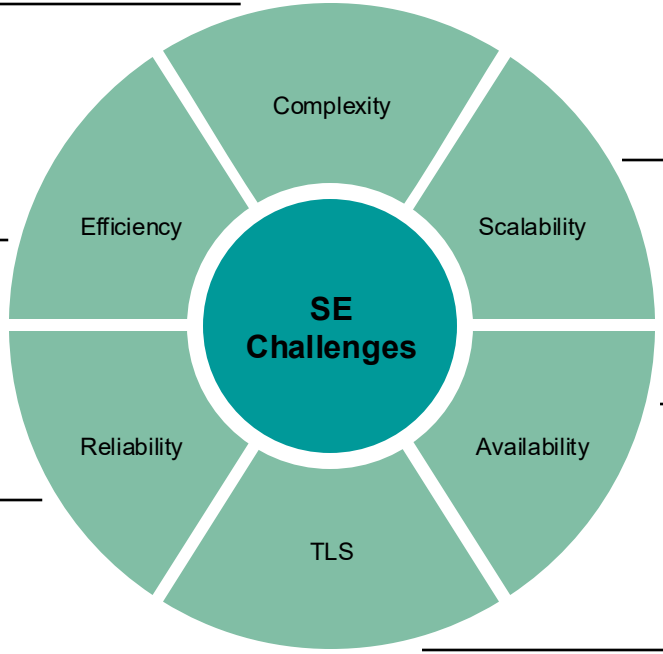
Model artifacts and relationships help manage complexity by enabling different views of the system

Operational Efficiency

Operational view and parameters can be generated and used as a driver of cost of maintenance

System Reliability

Reliability metrics based on current status of the asset integrated in model, predicted reliability of every capacity integrated in the model



Scalability

Model portions can be reused and copied, library of models available

Mission Availability

Mission success to be evaluated in terms of capabilities that can be evaluated in the model

Through Life Support

Simulation, machine learning and other tools to be applied to improve Through Life Support

Challenge integrated in model based approach

Document Based Verification Request Process

Average Lead Time 2-14 days. Every simulation run requires the same process.

Model-Based Verification Request Process

Average Lead Time 2-10 days when creating/updating the model..

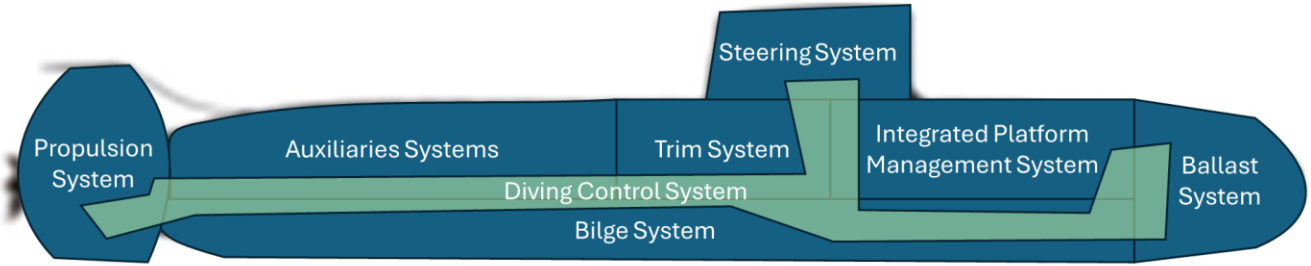
Average Lead Time < 1 day if simulation update is not required.

Project Introduction

- Diving Control System
- Integrated Sustainment System
- Objectives

Diving Control System Complexity

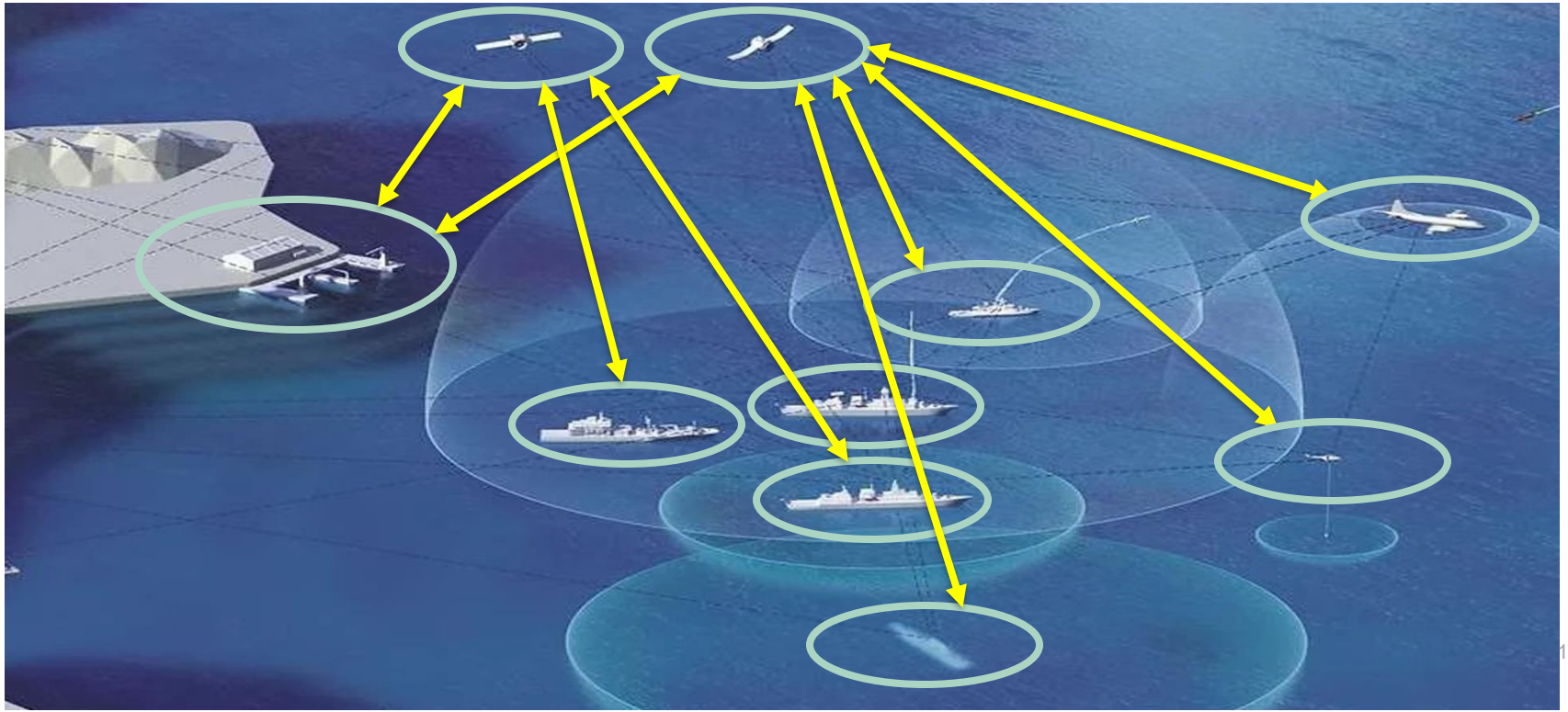
System of Interest (SoI)



- Integrates several subsystems but is developed using DBSE
- Not managed as a distinct subsystem within the S80 Product Breakdown Structure
- Design intent captured in disparate documents
- Plays a key role in ensuring the reliability, availability and safety of the S80 class units
- Need to capture well-formed system representation in digital models
- Modular system architecture and libraries

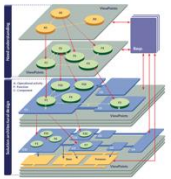
The Vision for Integrated Sustainment System

Complex maritime environments demand modular approach

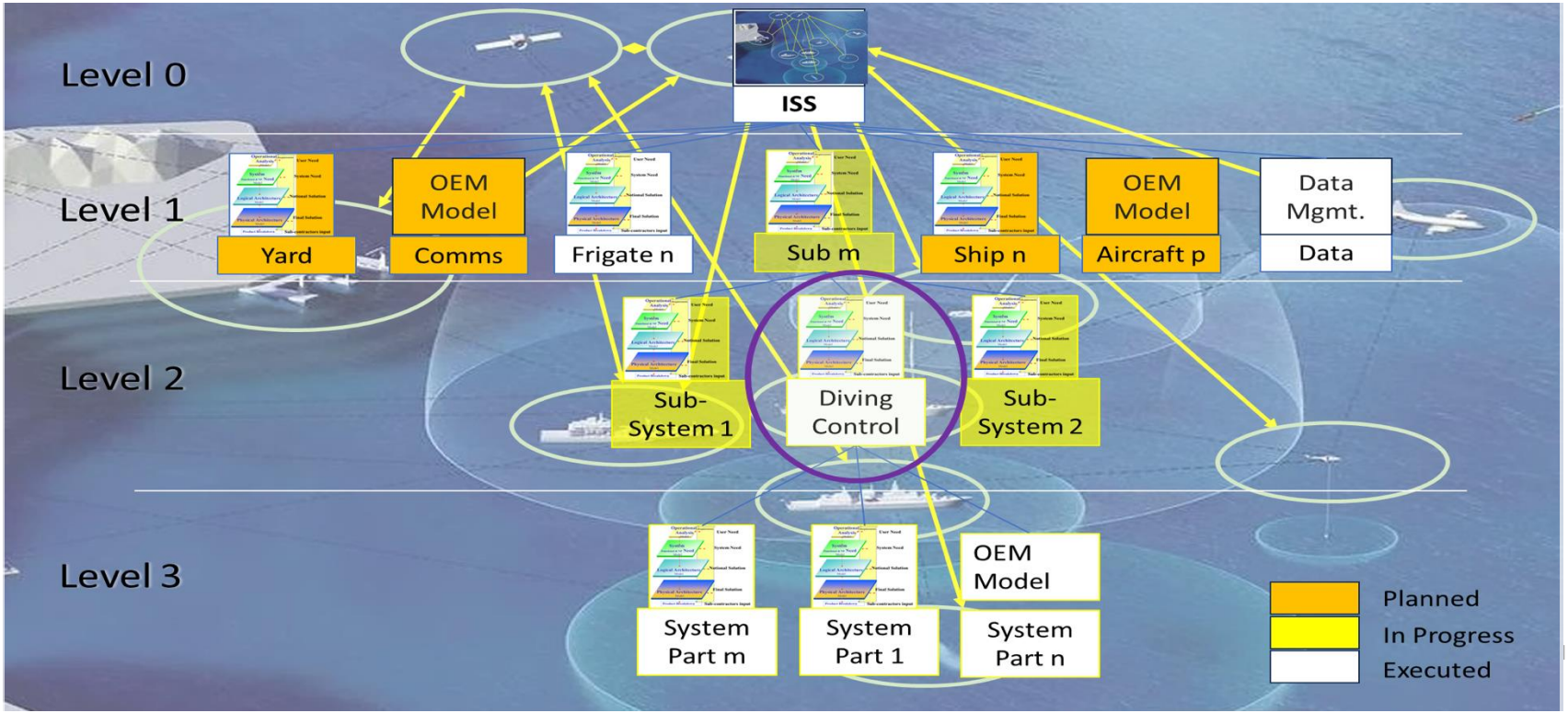


The Vision for Integrated Sustainment System

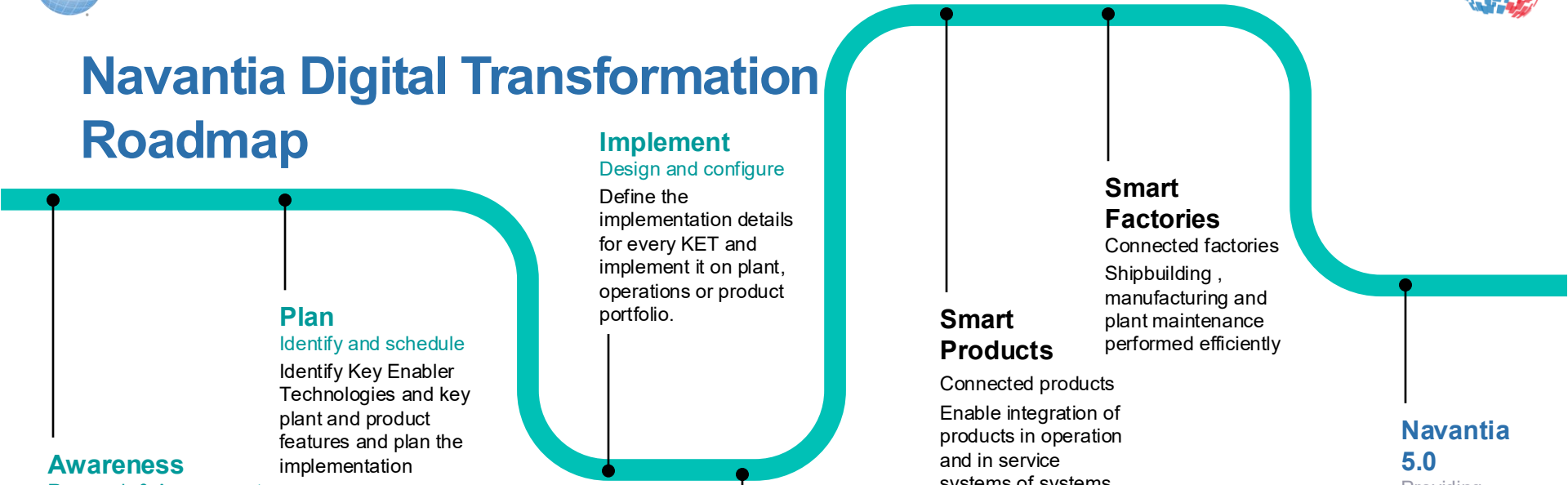
Complex maritime environments demand modular approach



Arcadia Method



Navantia Digital Transformation Roadmap



Awareness
Research & Assessment
Study and develop the available technologies and its use in Shipbuilding

Plan
Identify and schedule
Identify Key Enabler Technologies and key plant and product features and plan the implementation

Implement
Design and configure
Define the implementation details for every KET and implement it on plant, operations or product portfolio.

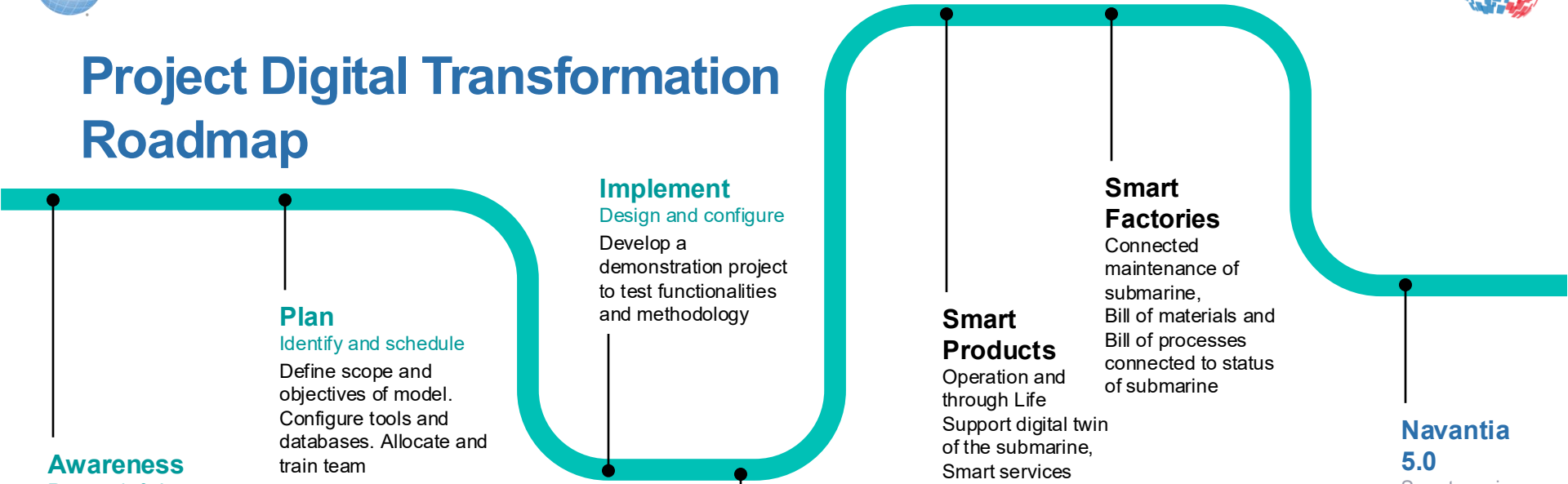
Digital Platform
Data based operations
State-of-the-art PLM and ERP to support product design and support and plant management.

Smart Products
Connected products
Enable integration of products in operation and in service systems of systems.

Smart Factories
Connected factories
Shipbuilding , manufacturing and plant maintenance performed efficiently

Navantia 5.0
Providing advanced products developed in advanced factories

Project Digital Transformation Roadmap



Awareness
Research & Assessment
Acquisition of MBSE tools methodology and skills to develop TLS project

Plan
Identify and schedule
Define scope and objectives of model. Configure tools and databases. Allocate and train team

Implement
Design and configure
Develop a demonstration project to test functionalities and methodology

Digital Platform
Data based operations
State-of-the-art PLM and ERP to develop product support, asset data acquisition and plant management.

Smart Products
Operation and through Life
Support digital twin of the submarine, Smart services enabled.

Smart Factories
Connected maintenance of submarine, Bill of materials and Bill of processes connected to status of submarine

Navantia 5.0
Smart services available for S80

Objectives

1. To define a structured process for model-based system verification that can be applied to sustainment

2. Develop the system architecture definition for the DC System and integrate it within the SoS hierarchy

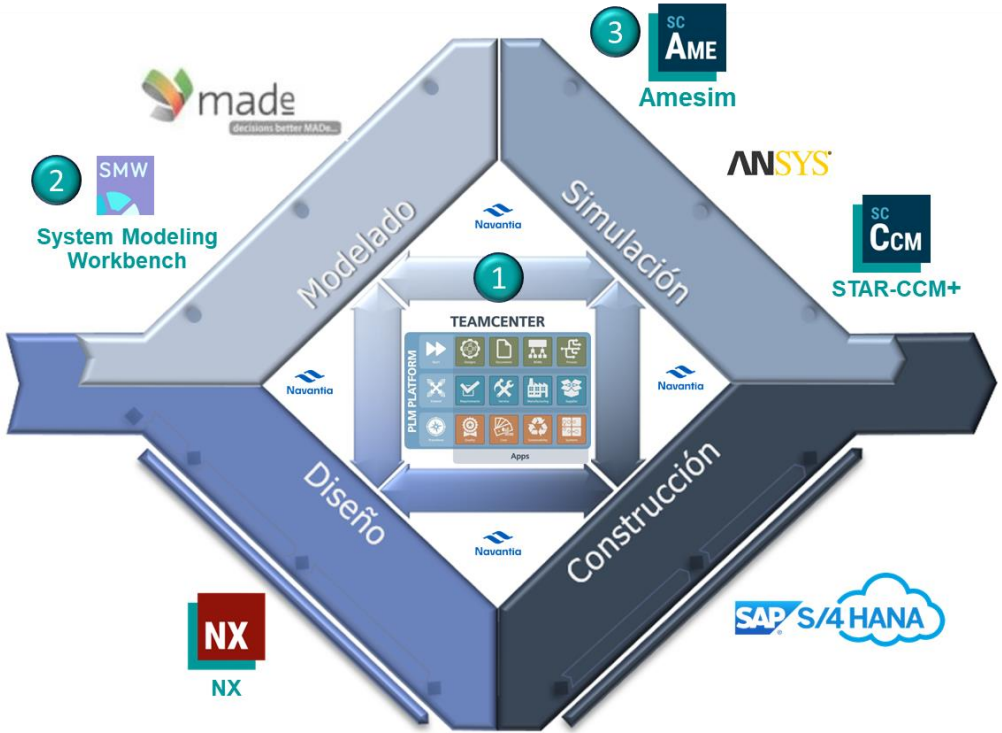
3. Assess the architecture for the reliability, availability and safety use cases by:
   - developing dedicated verification packages with relevant datasets for each use case
   - developing dynamic simulation models to assess performance for each use case

Methodology

- MBSE Tools
- Process Roles
- Process Flow & Results

Process Tools

- MBSE Orchestration:
  Teamcenter
- System Architecture Authoring:
  System Modeling Workbench
- System Simulation:
  Teamcenter Simulation,
  Simcenter Amesim



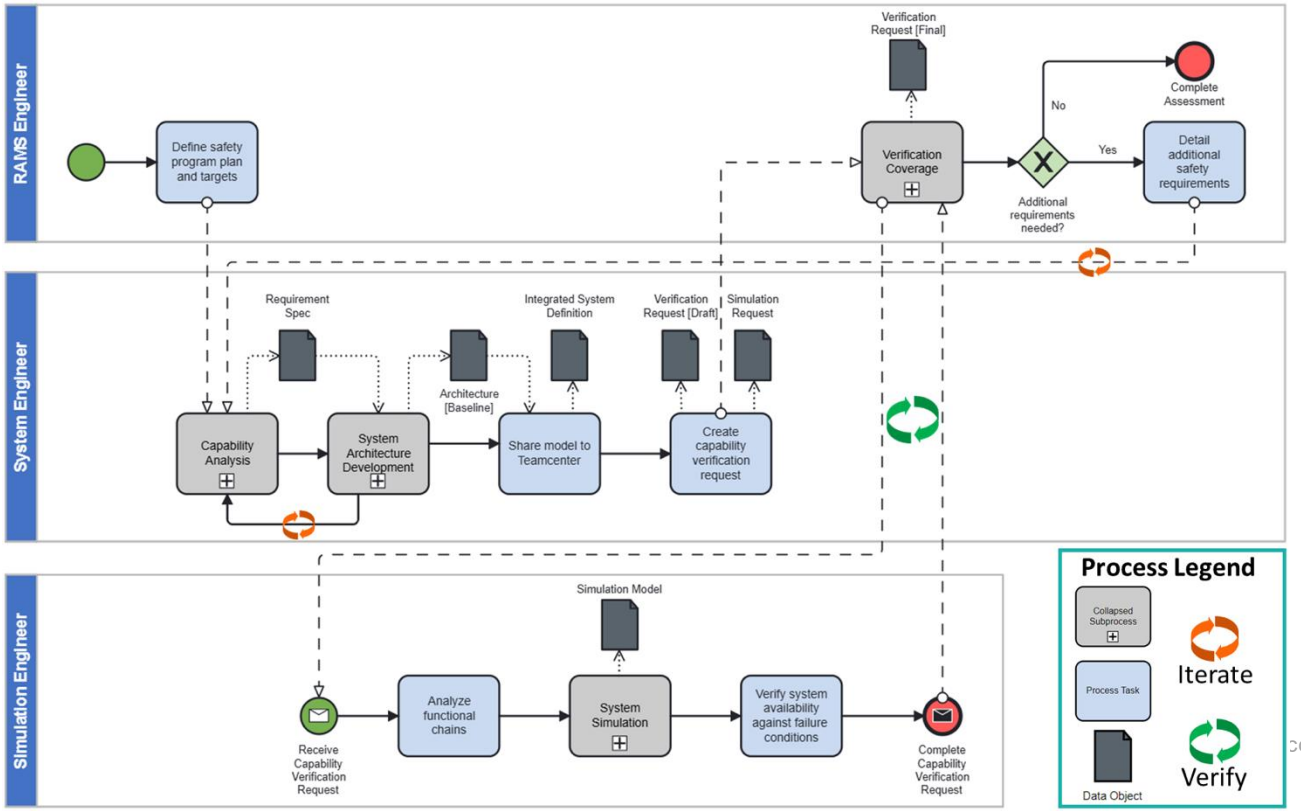
Process Roles

- **RAMS Engineer:**
  - responsible for defining program safety targets and milestones
  - collaboration with the System Engineer to review system requirements and targets and with the simulation engineer to verify the same

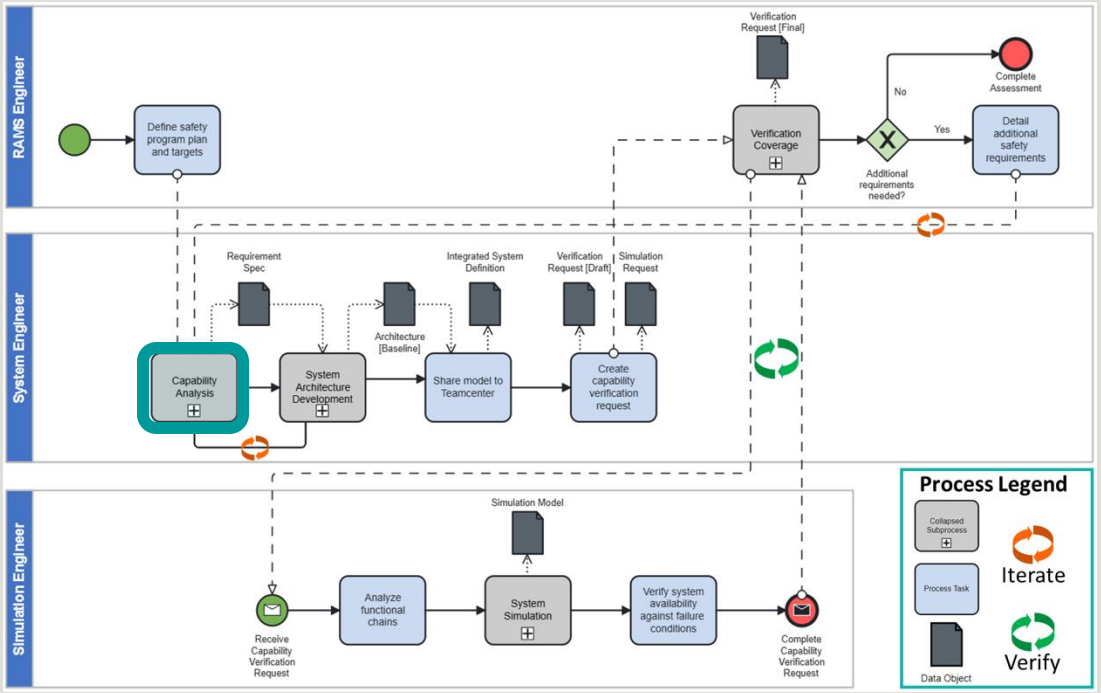
- **System Engineer:**
  - responsible for defining the system architectures, allocating requirements and managing the lifecycle of model artifacts in the integrated environment
  - creating architecture verification packages

- **Simulation Engineer:**
  - responsible for performing dynamic simulations of the control system
  - analyzing the failure modes based on the safety requirements and targets
  - verification reporting

Process Flow



Capability Analysis



Inputs:

- Enterprise safety program plan, safety targets, schedules
- MBSE orchestration environment readiness
- Reusable architecture description documents

Activities:

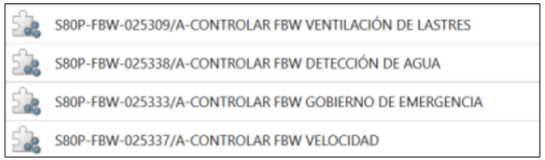
- Operational capability definition (capability BOM)
- System modeling scope definition per capability

Outputs:

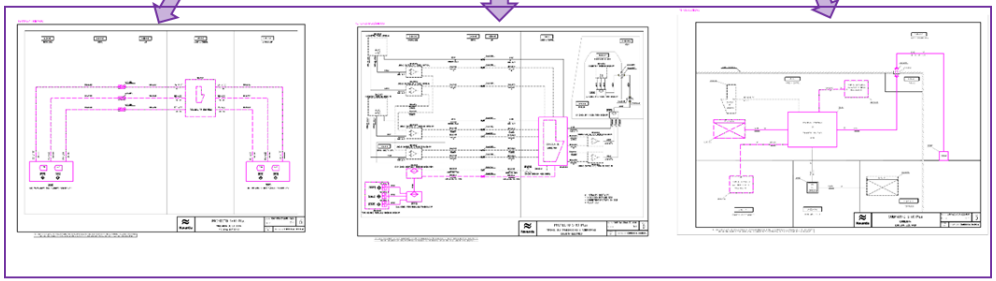
- Capability BOM (configurable)
- System modeling work plan

Capability Analysis

Operational Capabilities BOM

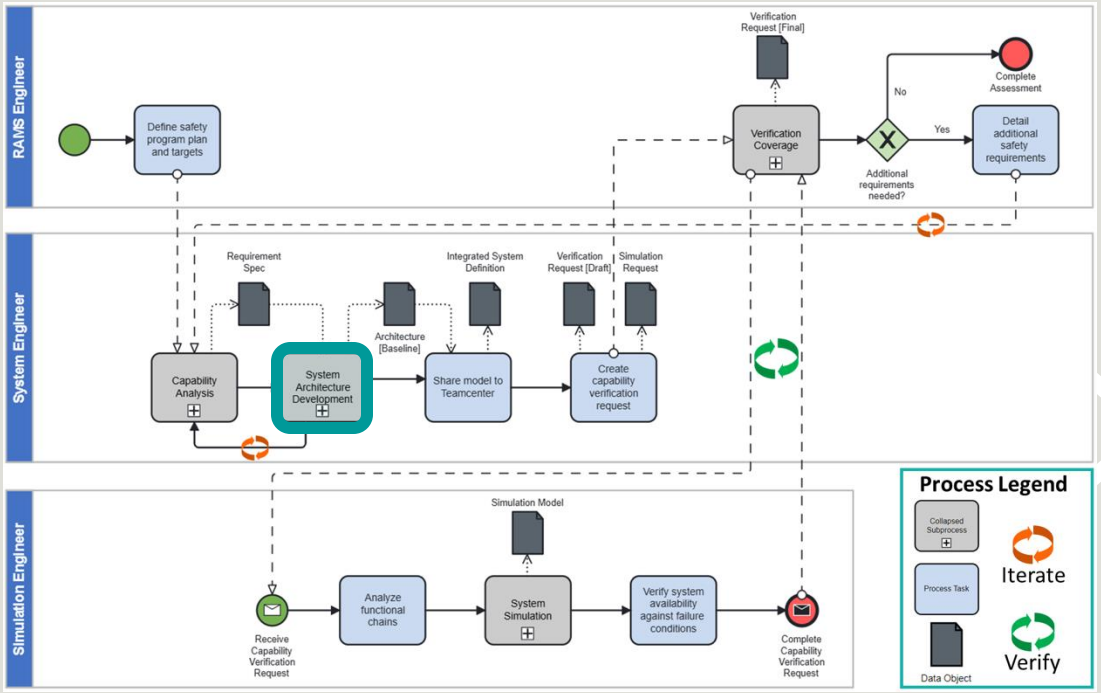


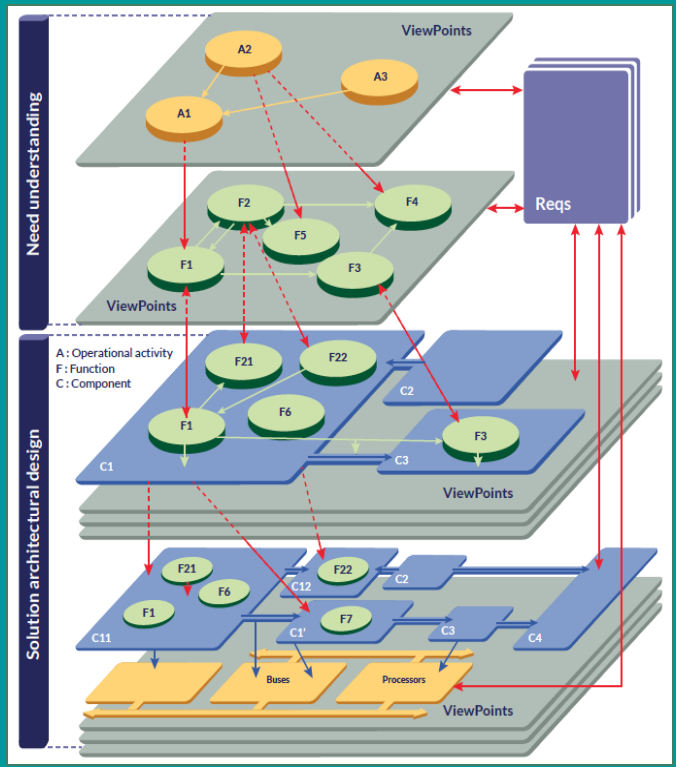
System scope per capability



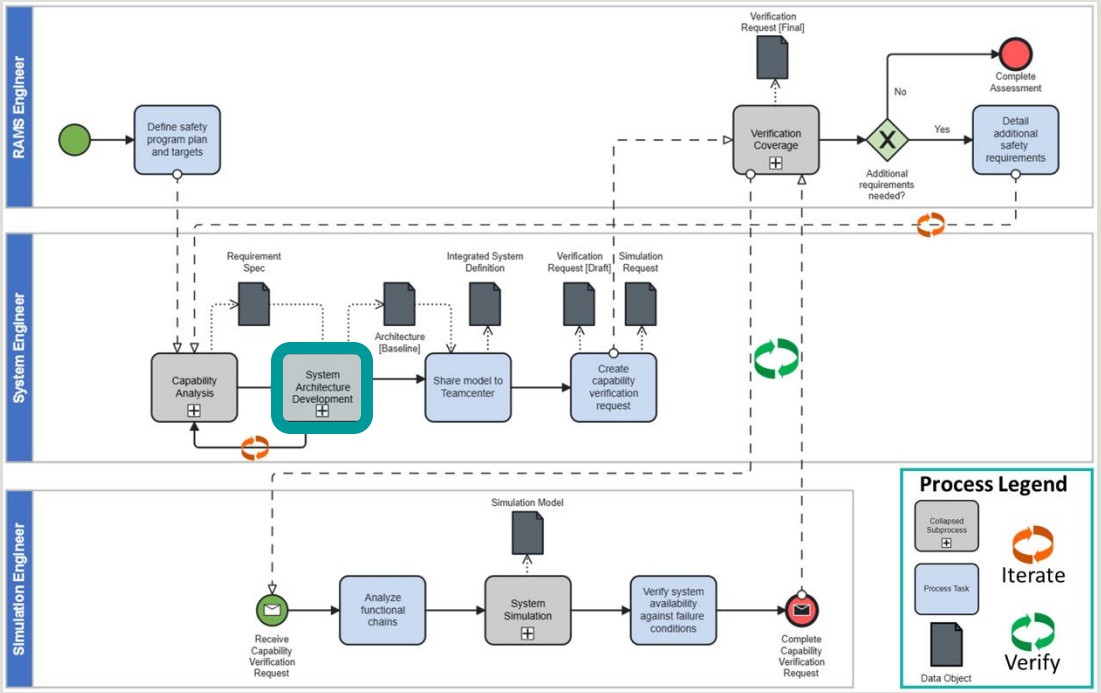
Modeling Workplan Definition

System Architecture Development





System Architecture Development (Operational Analysis)



Inputs:

- SoS, mission, stakeholder requirements
- REM (Navy Staff Requirements)

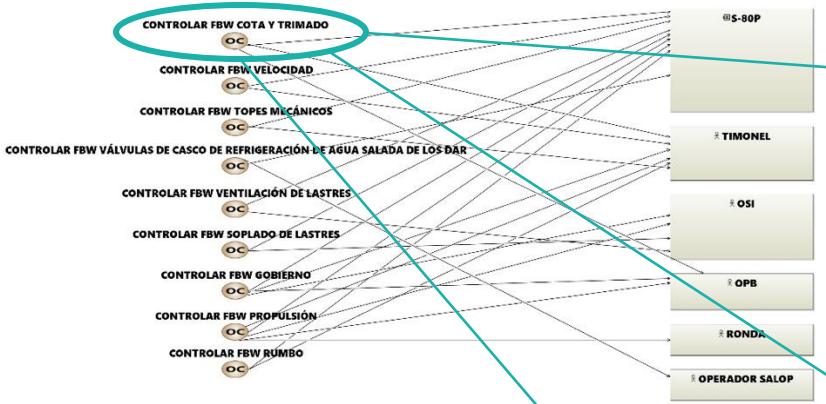
Activities:

- Model SoS capabilities
- Define operational behavior
- Define operational architecture
- Refine / allocate stakeholder needs
- Analyze operational model

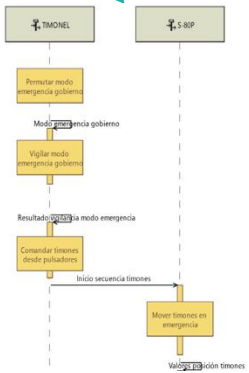
Outputs:

- Operational interface constraints
- Refined SoS requirements

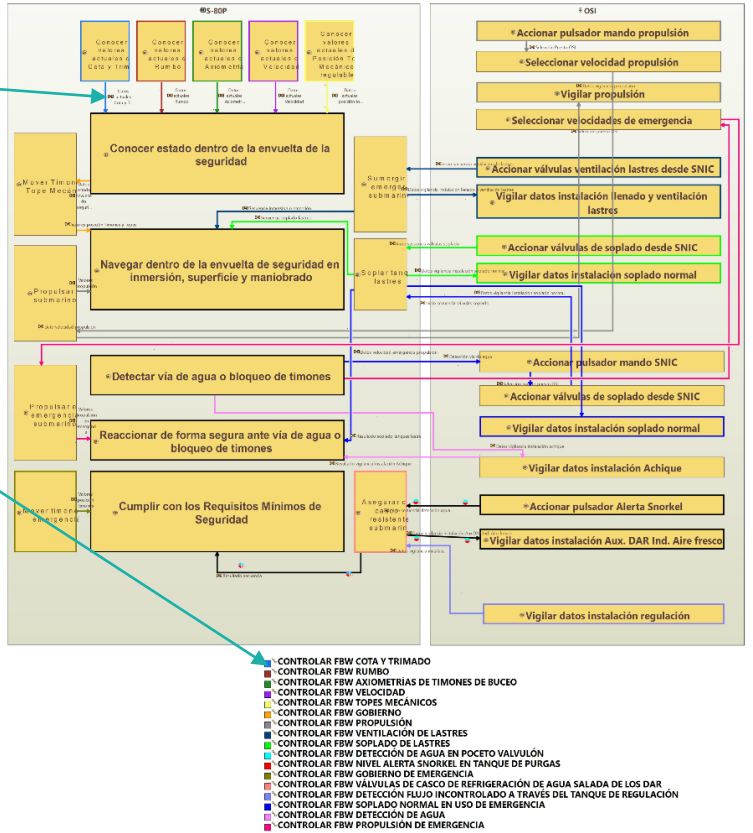
Operational Analysis



SoS Operational Capabilities BOM

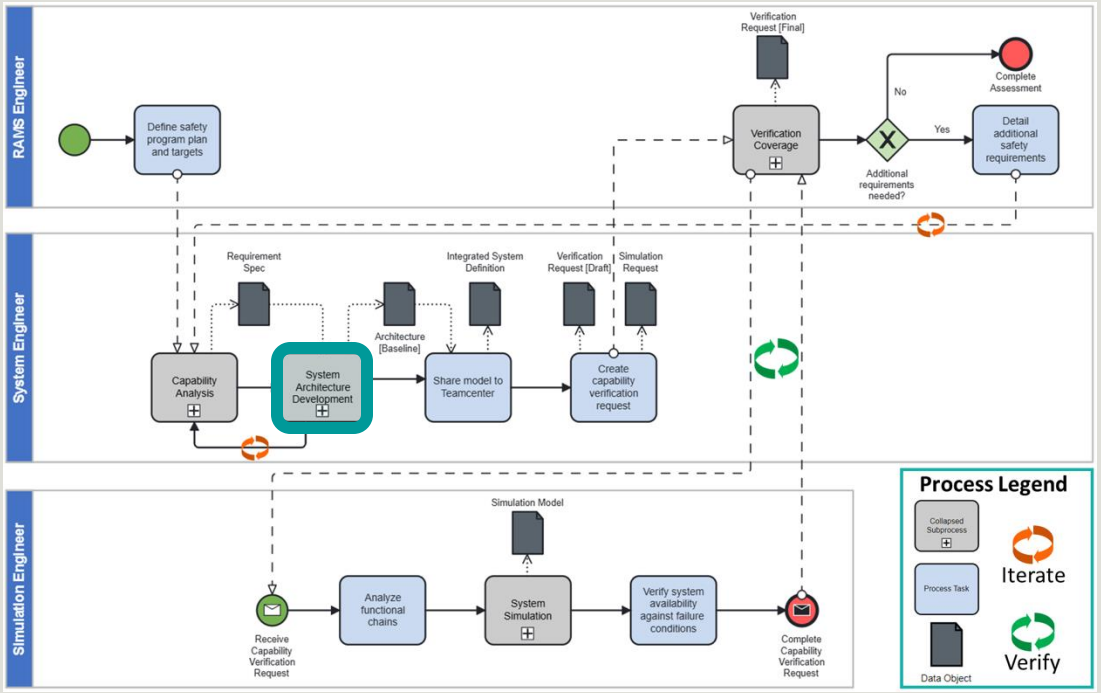


SoS Operational Scenario



Operational Context (architecture)

System Architecture Development (System Analysis)



Inputs:

- Operational architecture
- System capabilities

Activities:

- Model system capabilities
- Define and allocate system/actor functions
- Contextualize system-of-interest
- Generate SA views

Outputs:

- Blackbox architecture model (configurable)
- System requirements spec
- Functional scenarios spec

System Analysis

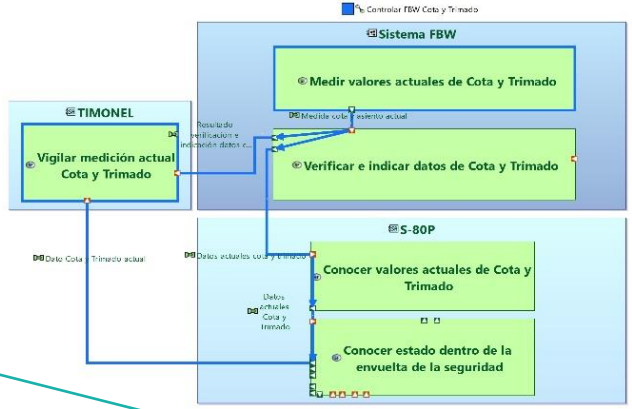
Misión: Control remoto de las funciones necesarias para permitir al submarino hacer inmersión, superficie y maniobrar dentro de los límites de la Envolvente de Seguridad

Sistema FBW

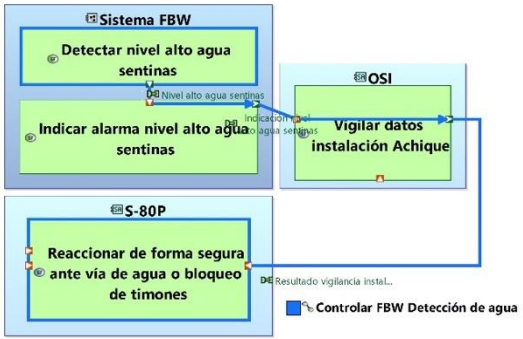
- CONTROLAR FBW COTA Y TRIMADO
- CONTROLAR FBW VELOCIDAD
- CONTROLAR FBW TOPES MECÁNICOS
- CONTROLAR FBW VENTILACIÓN DE LASTRES
- CONTROLAR FBW SOPLADO DE LASTRES
- CONTROLAR FBW PROPULSIÓN
- CONTROLAR FBW GOBIERNO
- CONTROLAR FBW RUMBO
- CONTROLAR FBW DETECCIÓN DE AGUA
- CONTROLAR FBW GOBIERNO DE EMERGENCIA

DC System Capabilities

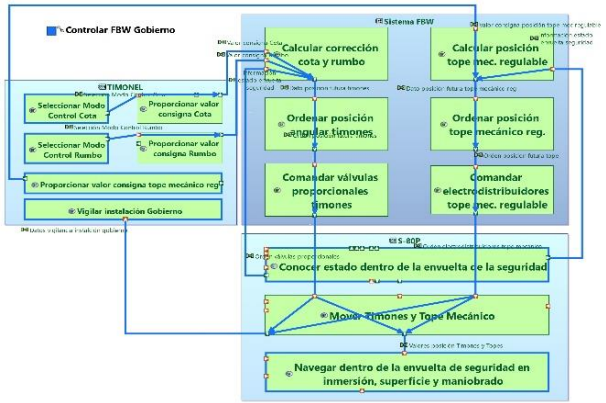
Control Depth



Control Water Detection

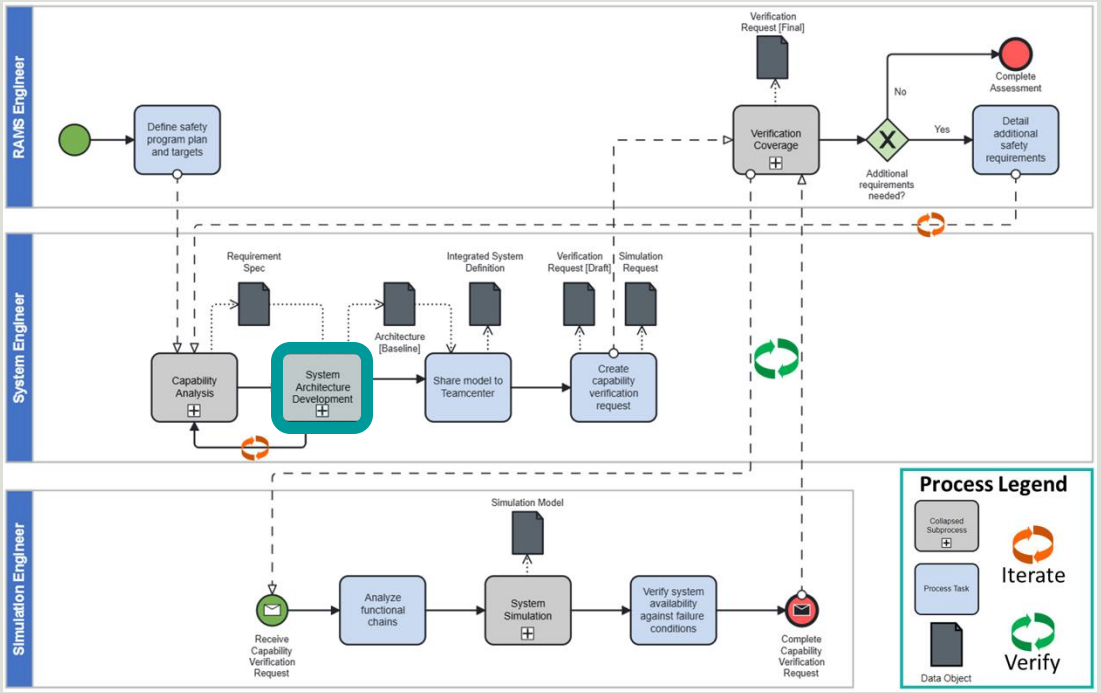


Control Rudders



Capability Architecture Views

System Architecture Development (Logical Architecture)



Inputs:

- Blackbox system architecture
- DC system requirements

Activities:

- Decompose logical system
- Allocate functions to logical components
- Define internal interfaces (white box)
- Generate stakeholder concerns (views)
- Requirement / parameter traceability

Outputs:

- Logical architecture model (configurable)
- Performance allocation & traceability
- Performance verification views

Logical Architecture

Misión: Control remoto de las funciones necesarias para permitir al submarino hacer inmersión, superficie y maniobrar dentro de los límites de la Envolvente de Seguridad

Sistema FBW

- CONTROLAR FBW COTA Y TRIMADO
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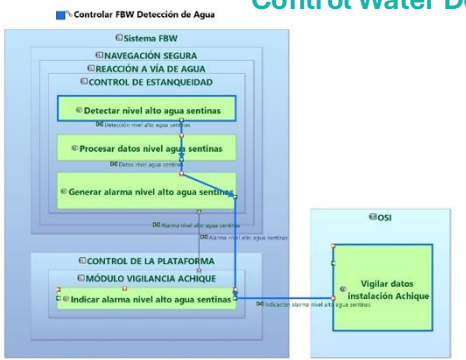
- CONTROLAR FBW RUMBO
- CONTROLAR FBW DETECCIÓN DE AGUA
- CONTROLAR FBW GOBIERNO DE EMERGENCIA

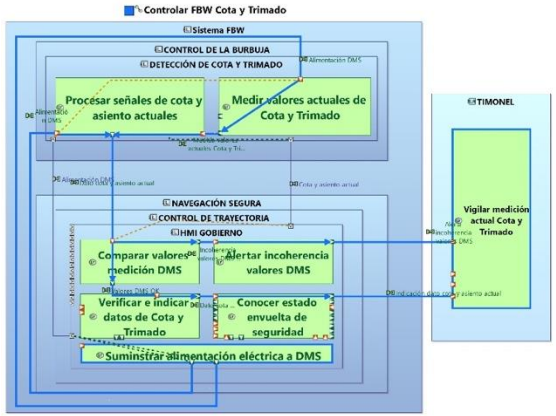
System Capabilities BOM

Logical Structure in PLM

Control Water Detection

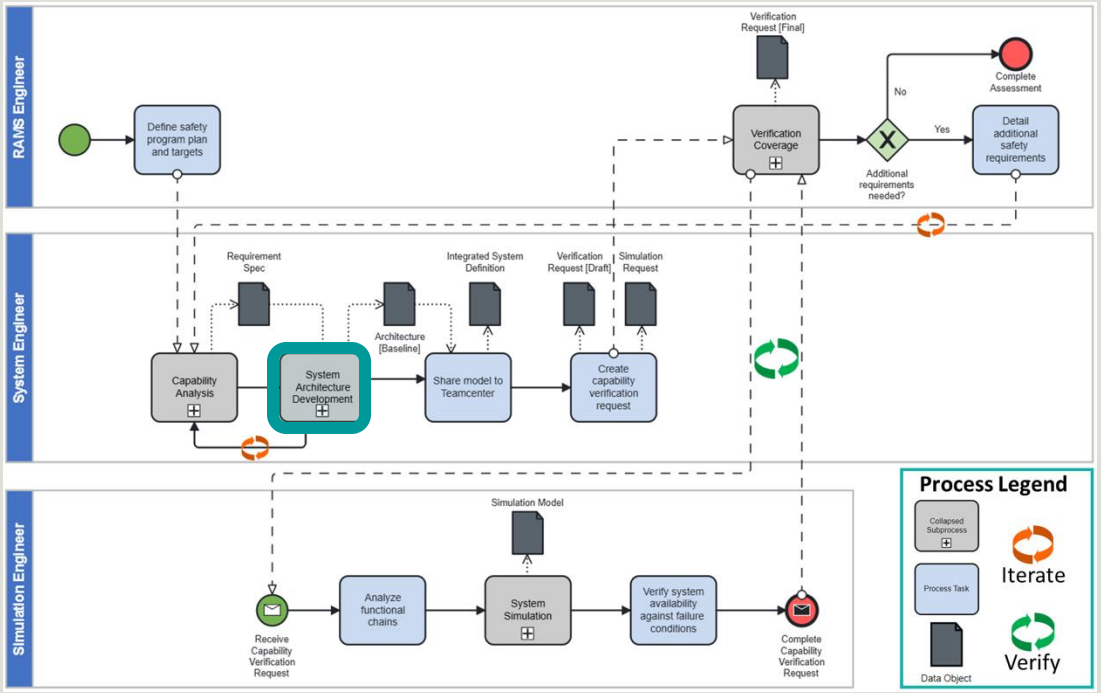


Control Depth



Logical Architecture Views

System Architecture Development (Physical Architecture)



Inputs:

- Logical architecture
- Subsystem requirements (draft)

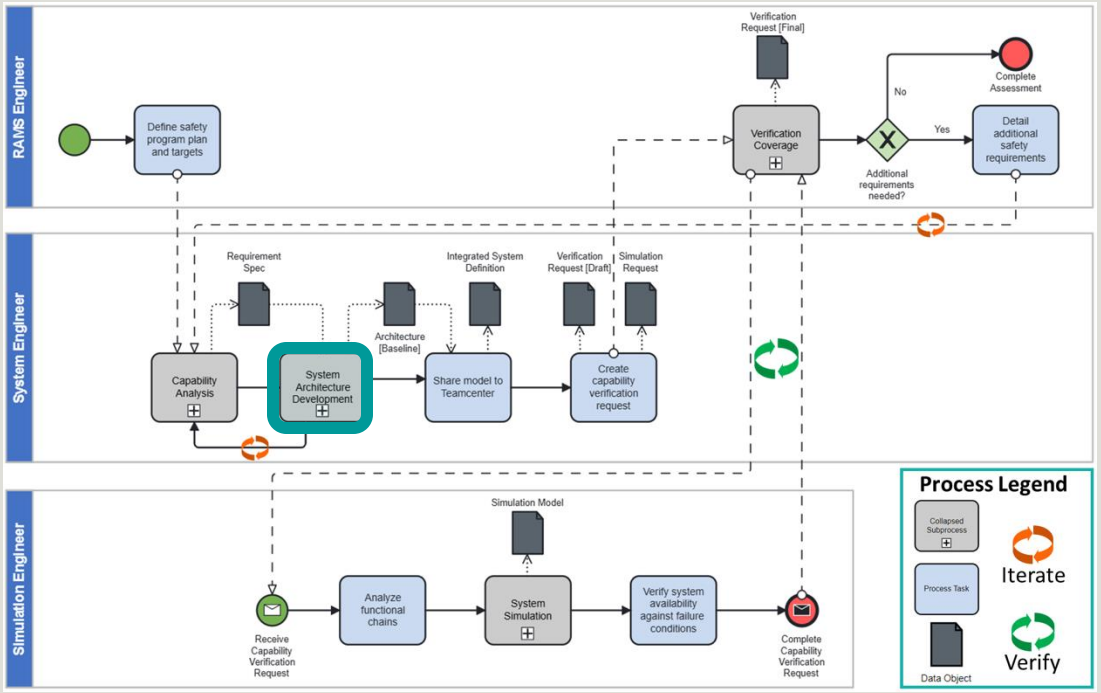
Activities:

- Perform system to subsystem transitions
- Generate reusable subsystem libraries
- Allocate logical components to physical components
- Generate physical architecture views
- Save libraries to PLM

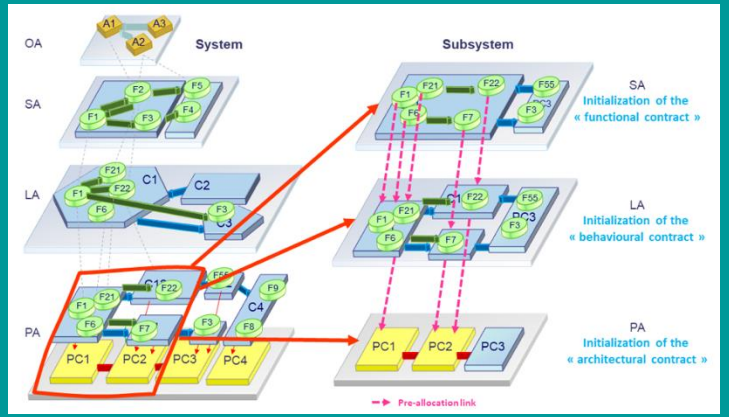
Outputs:

- Physical architecture model (configurable)
- Preliminary PBS

System Architecture Development (Physical Architecture)



Automated system to subsystem transitions

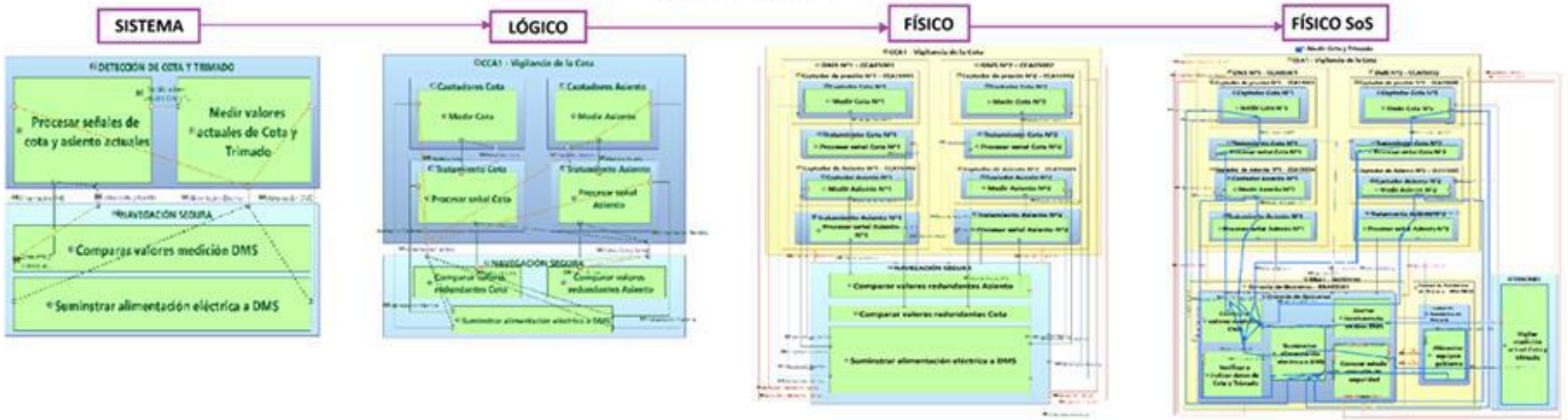


System **Subsystem**

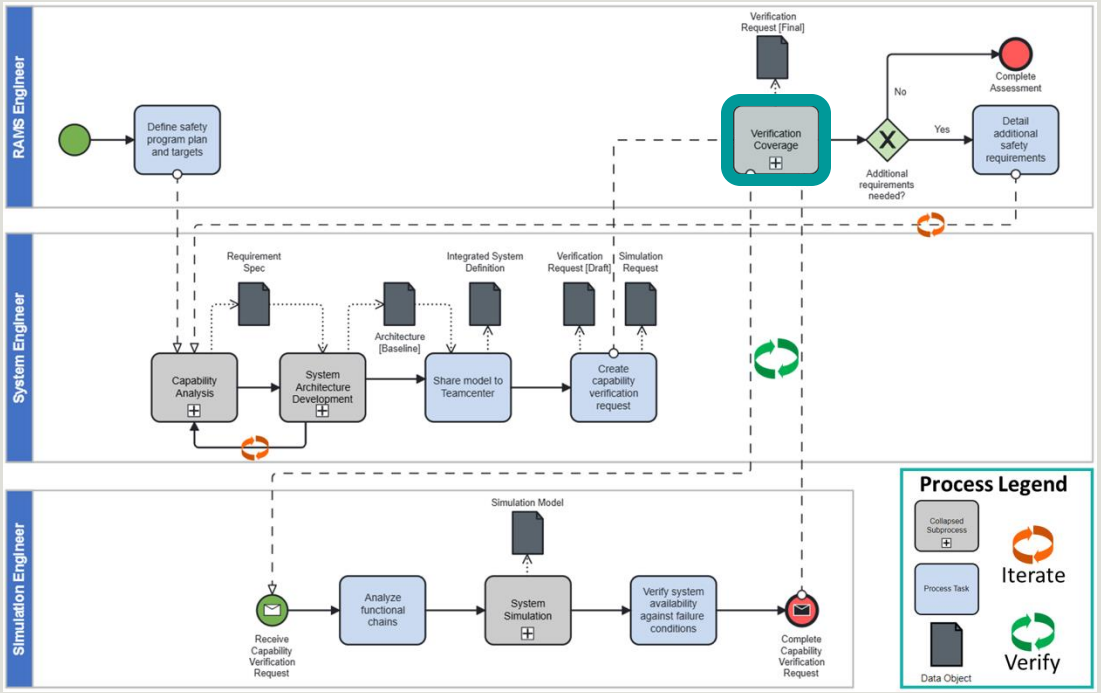
Physical Architecture

Librería Subsistema CCA1

023073/A - CCA1 - Vigilancia de la Cota



Verification Coverage



Inputs:

- Physical architecture model for performance simulation
- Simulation requirements, input/output parameters, variables

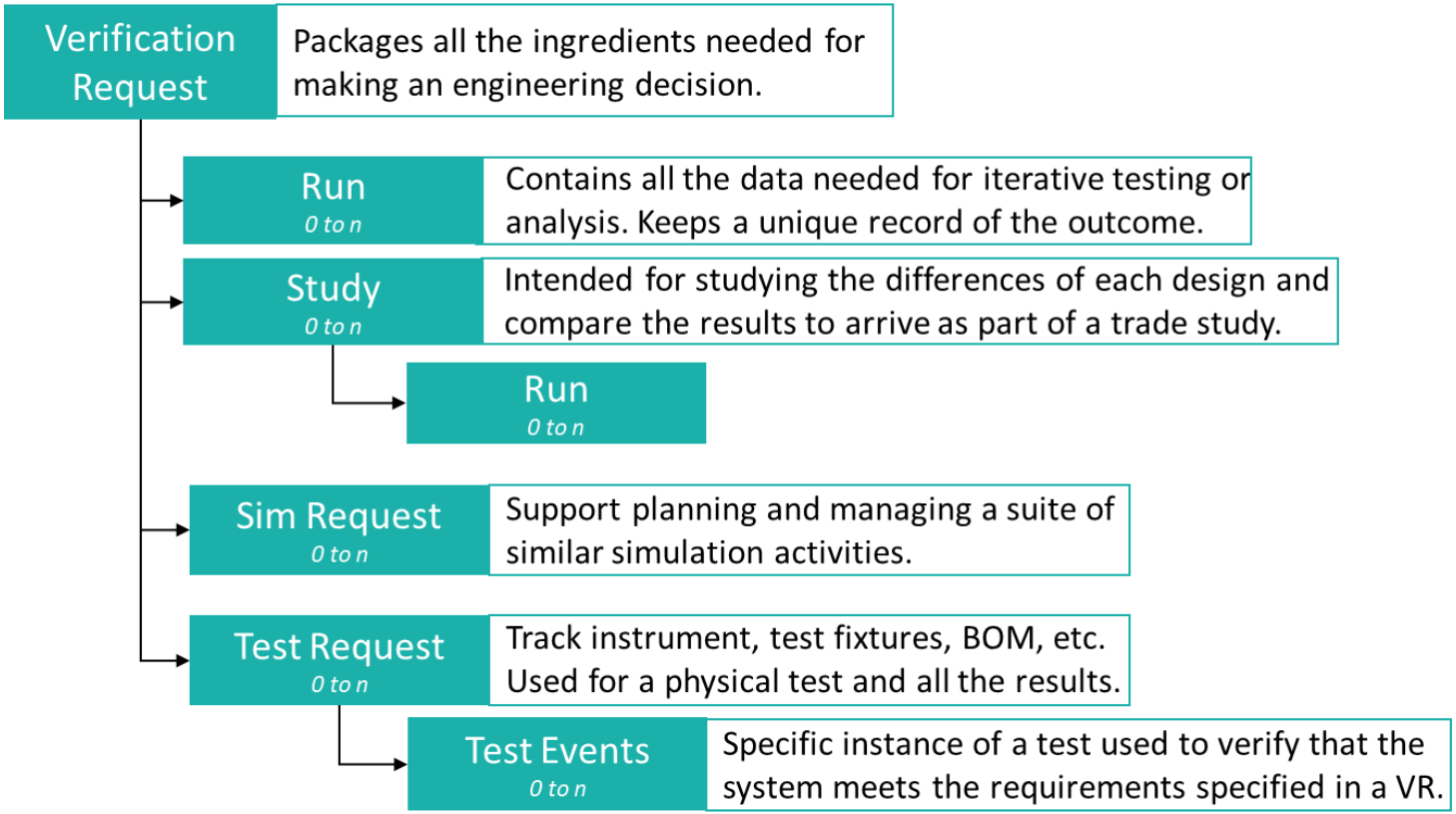
Activities:

- Create verification request packages
- Define simulation requests corresponding to functional chains
- Ensure VR/SR coverage
- Submit VR to workflow

Outputs:

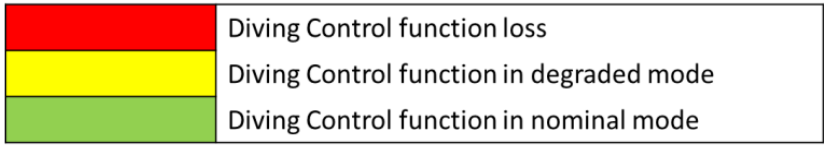
- Verification request package
- Attached verification assets

Verification Request Data Structure



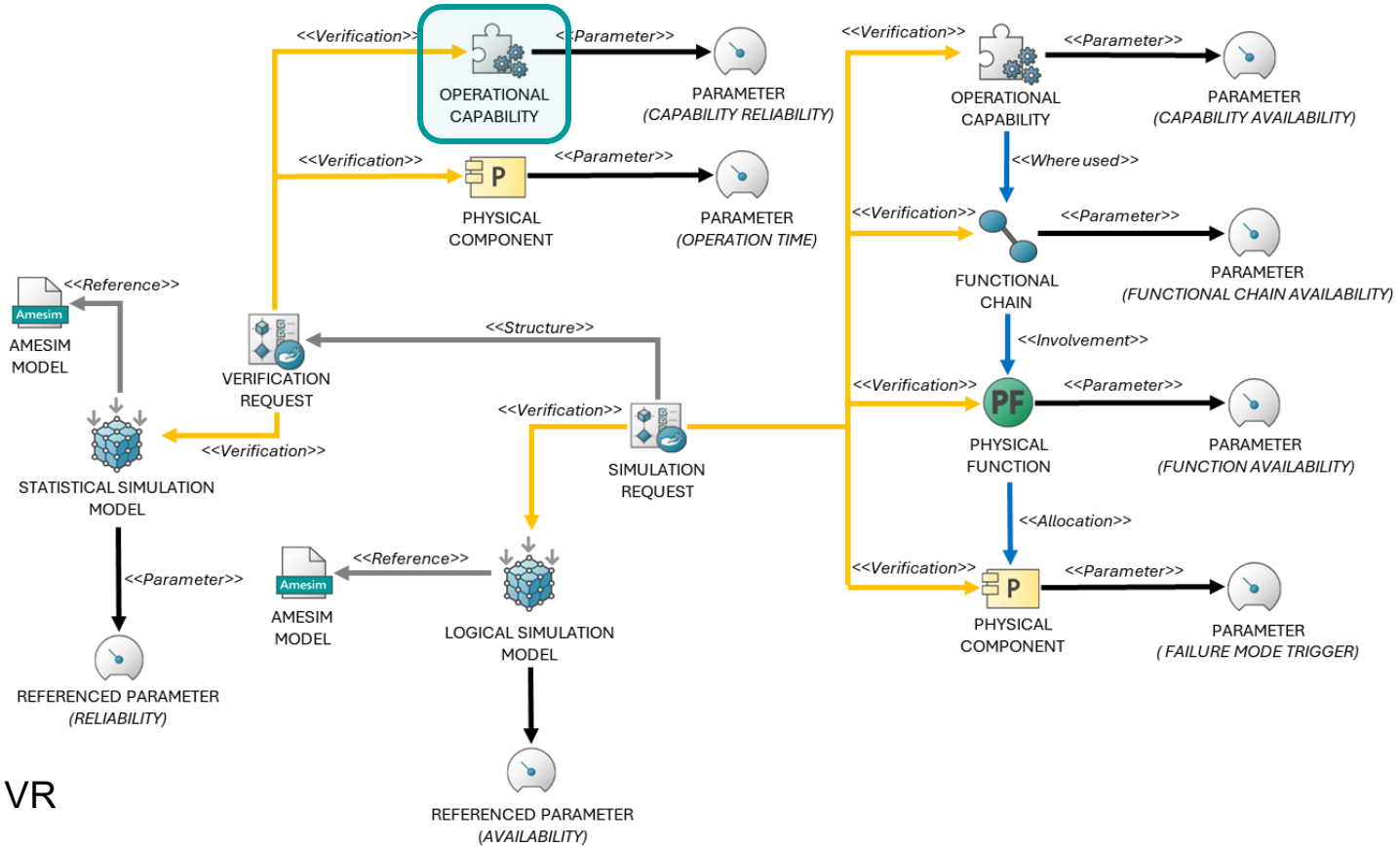
Verification Use Cases

1. **Assessment of the availability and reliability of the DC system based on the failure modes of the components (single failure):**
   - Traceability between operational capabilities, functional chains and physical systems
   - Verification request driven by operational capabilities of the S80
   - Logical simulation model to analyze reliability and availability
   - DC functional availability assessment based on state chart execution



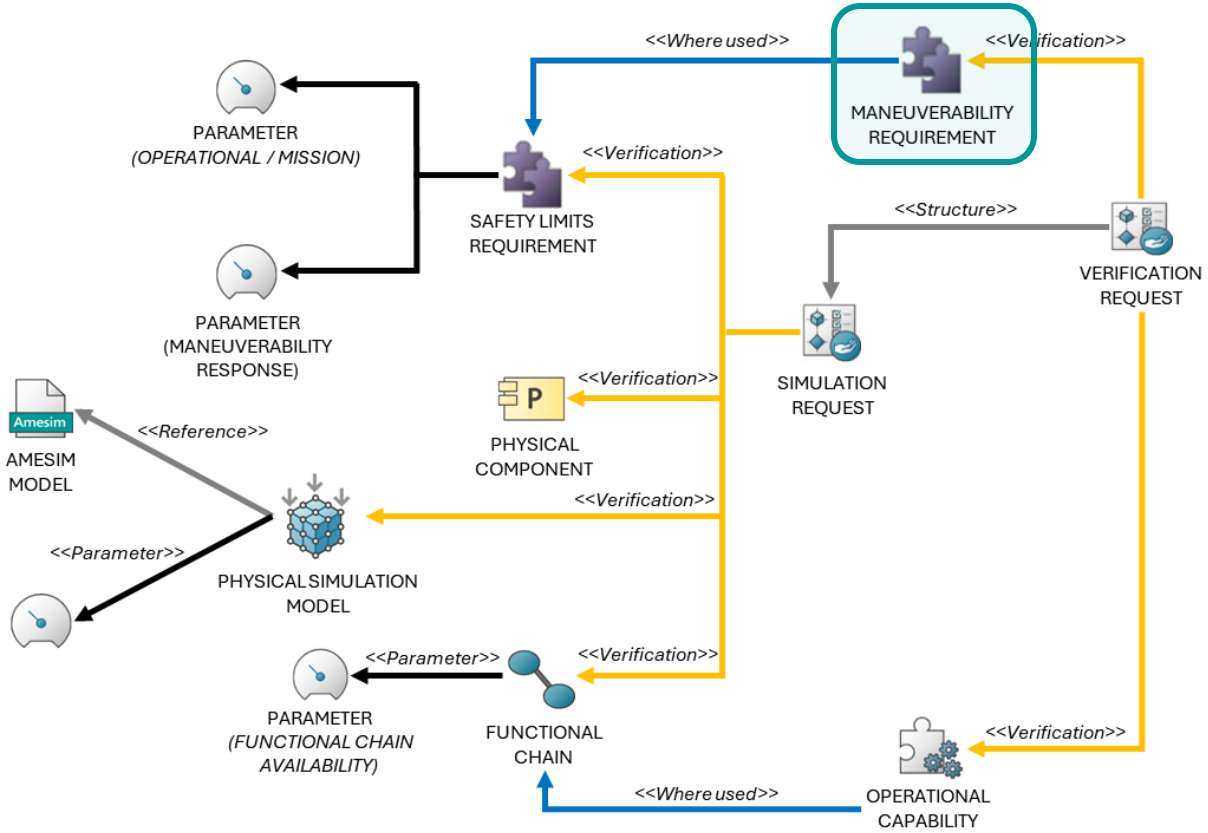
2. **Analysis of the response of the DC system to an external failure (casualty cases).**
   - Verification request driven by “Maneuverability” requirement
   - 1D simulation model to analyze system safety based on a set of casualty cases

Assessment of the availability and reliability of the DC system based on the failure modes of the components (single failure)



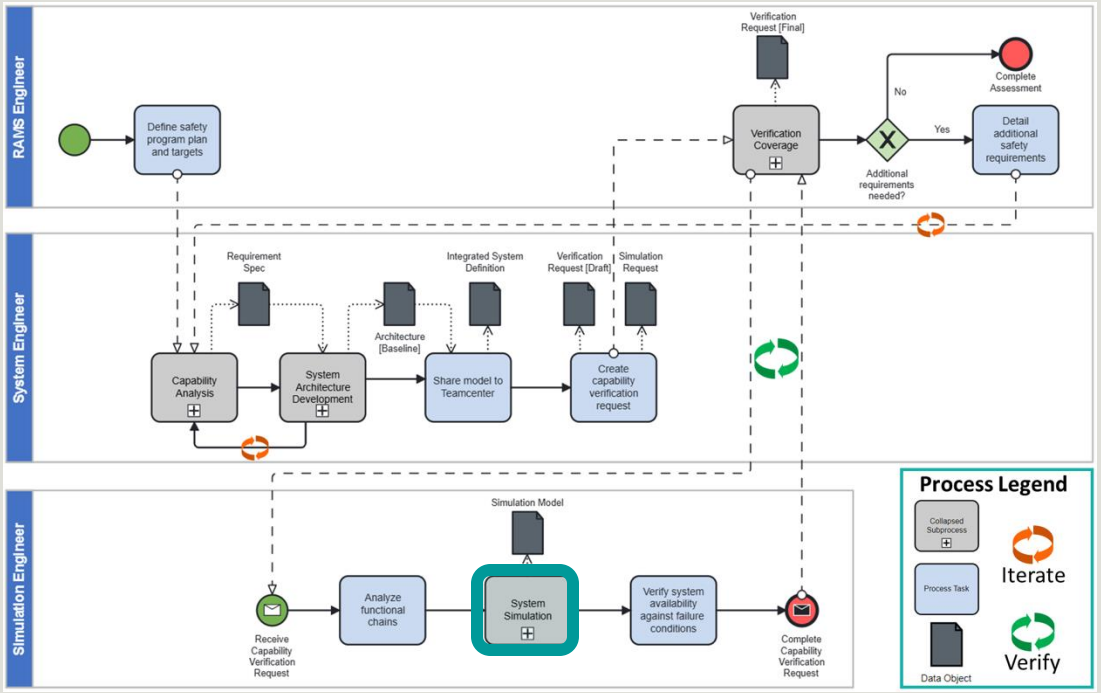
Initiate VR

Analysis of the response of the DC system to an external failure (casualty cases)



Initiate VR

System Simulation



Inputs:

- Verification request
- Integrated system definition including architecture artifacts
- Simulation requirements, reusable simulation models

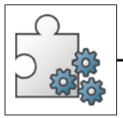
Activities:

- Launch simulation in managed mode
- Analyze system for reliability, availability and safety
- Report verification results

Outputs:

- Verification results
- Architecture refinement proposals

Assessment of availability and reliability of the DC system based on the failure modes of the components (single failure)



Capability verification object in Teamcenter (involving functional chains)

F110-005774/A-Controlar FBW Cota y Trimado
Controlar FBW Cota y Trimado
ID: 005774
Revision: A

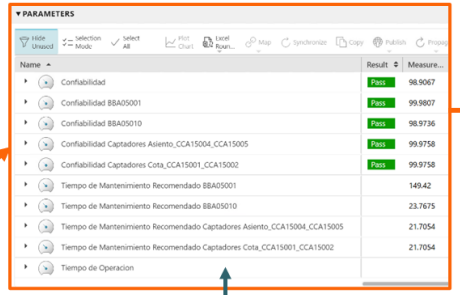
'Reliability' VR

Link

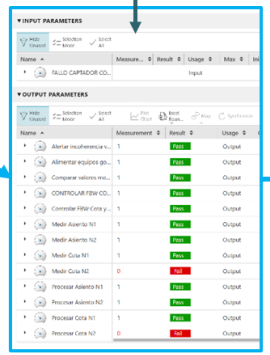
F110-019892/A-Medir Cota y Trimado - 1B1 (FALLO CAPTADOR COTA N1)
Medir Cota y Trimado - 1B1 (FALLO CAPTADOR COTA N1)
ID: 019892
Revision: A

'Availability' Simulation Request per failure mode

Reliability calculations based on Operation Time as Input

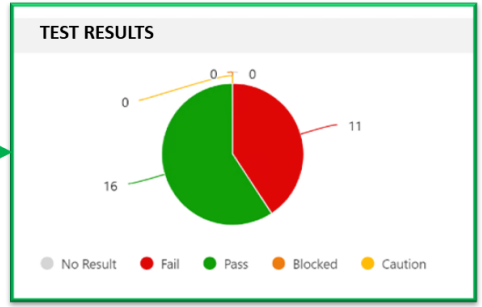


Availability & Reliability Simulation Model (Managed mode from Teamcenter)



Final Reliability Assessment on Capabilities

Name	Result	Type
CONTROLAR FBW COTA Y TRIMADO	Pass	Capability Revision



Name	Result
Medir Asiento N°2	Pass
Medir Cota N°1	Pass
Medir Cota N°2	Fail

Availability Assessment on Functions

CONTROLAR FBW COTA Y TRIMADO	Pass
Controlar FBW Cota y Trimado	Pass

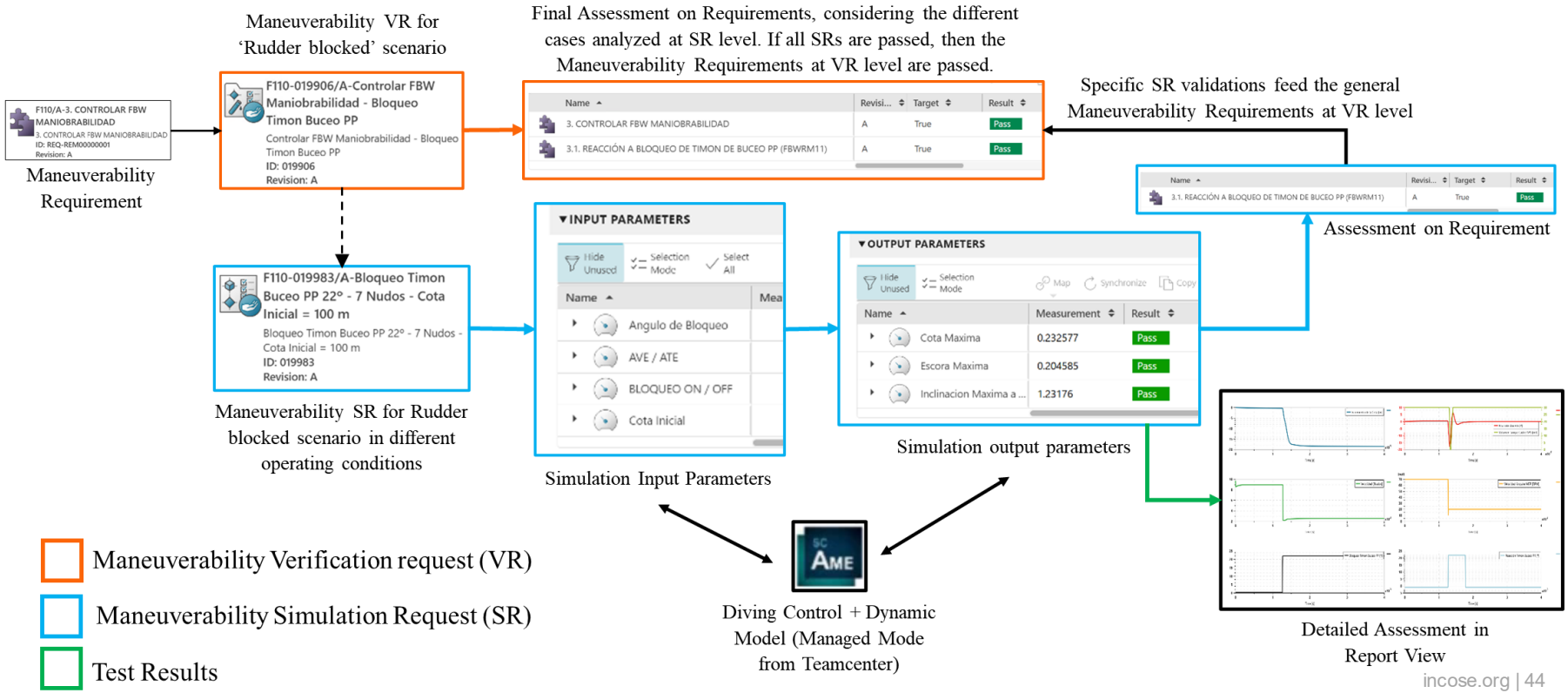
Final Availability Assessment on Capabilities and Functional Chains

Reliability Verification Request

Availability Simulation Request

Test Results

Analysis of the response of the DC system to an external failure (casualty cases)



Conclusion

- Lessons Learned
- Future Direction
- Additional Information

Lessons Learned

Immediate and perceived benefits

Availability Assessment
Quantitative availability assessment of system using a probabilistic approach

Reliability Assessment
Time-to-predicted-failure of each individual component

Safety Assessment
Casualty simulation
Pass/fail conditions

Reusability
Configurable modeling artifacts
Enterprise-wide mgmt. of assets

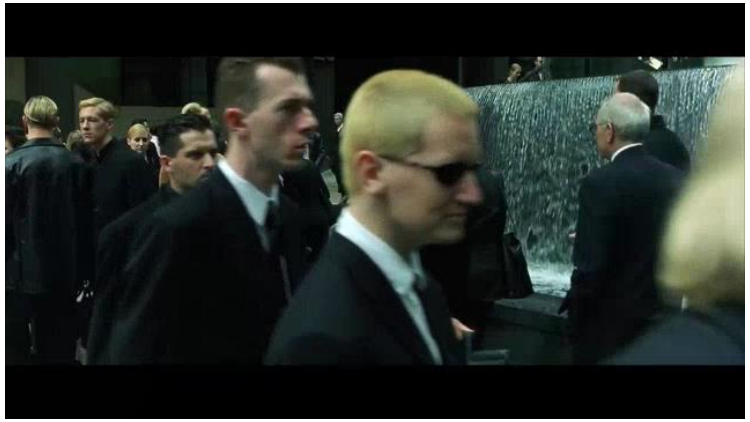
Model Fidelity
Scalability based on fidelity
Improved calculation accuracy

Model Scope
Scalability based on scope
Reusability in a complete submarine

The S80 Sustainment Program

The foundation of the digital twin, the structure

Front-End



- PLM, virtual mock-up
- Performance metrics
- Cost metrics
- Reliability metrics

Back-End

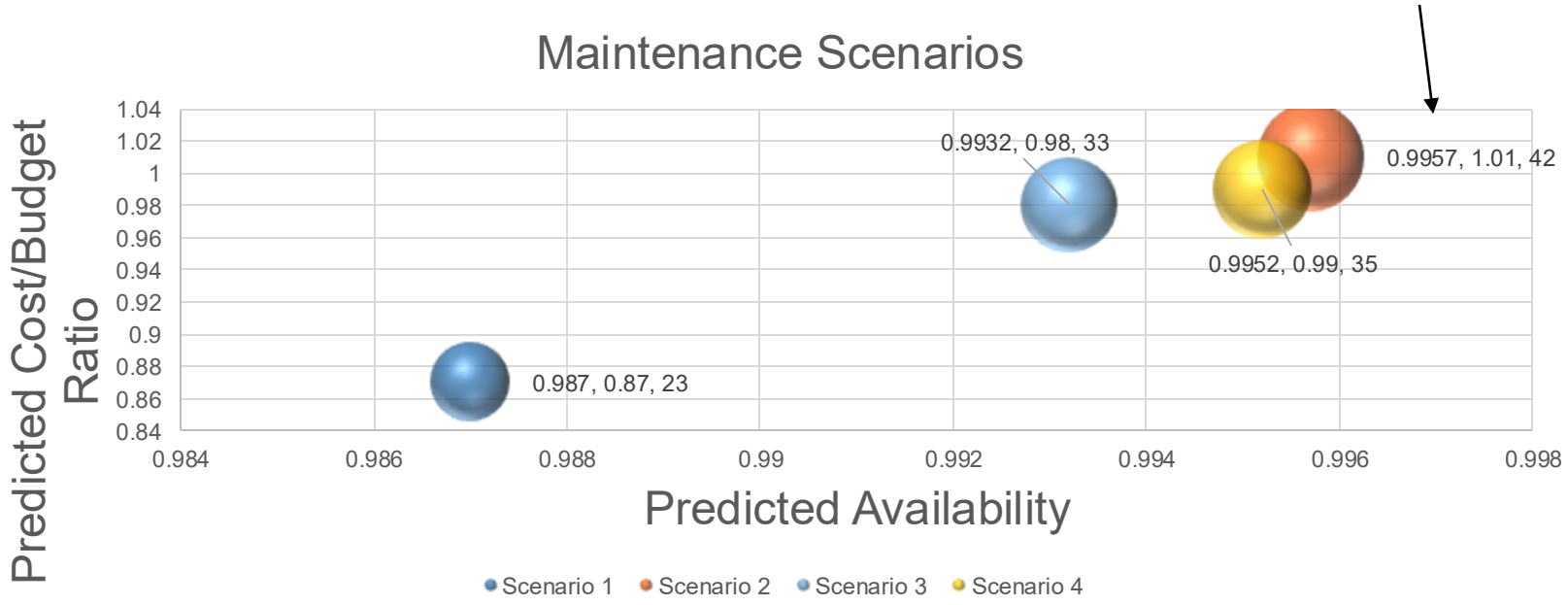
- Systems Engineering
- Configuration Management
- Simulation
- Data management

The S80 Sustainment Program

The foundation of the digital twin, the promise

Front-End (specimen)

Availability; Cost/Budget ratio; Shutdown days



Future Directions

Extending MBSE across the Navantia enterprise and beyond

- **Project Level:**
  - Complete model of S80 submarine
  - Focus on trading-off maintenance scope scenarios for efficient budget allocation
- **Corporate Level:**
  - MBSE Framework including standard configuration, model governance, business rules, best practices, model libraries and infrastructure support – from concept design to disposal
  - Foster reuse of models and model-based design, building and product support
- **European Defense Level:**
  - Common framework for naval vessels ship digital architecture, digital platform and digital engineering processes (EDINAF)
  - Common digital thread across companies, institutions and ministries of defense

Observations

- Navantia products have longer lifecycle (~40 years), with heavy configuration changes over the life cycle - which makes it a valuable case for implementing MBSE
- Document-based SE approach is not suitable to cover operation, and sustainment needs as far as deliverables are product oriented and information is siloed
- Model Based SE provides the tools, methodology and functionalities to cover sustainment needs by providing a common and accessible data configuration that can be much more easily exploited
- Beyond concept & development, MBSE offers equal if not more value in the operations phase of the life cycle
- Implementation of MBSE requires tools, methodology and a change of culture of the team

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Thank you!

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