MBSE Data Interoperability - Architecture Model Exchange Solutions

Phase 3 Team Report-Out, September 2020

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MBSE Data Interoperability

Introduction

- **Problem Statement**

  Currently there are no standards-based tools that support the exchange of digital system architecture models across the aerospace industry. The Aerospace OEMs and their Suppliers have not identified a common solution that enables their transition to a collaborative model-based business process.

- **Project Objectives**

  To evaluate, identify, and promote methods of exchanging digital engineering design content, including system architecture models.

Artifact Definitions

MBSE Working Team Perspectives

- System Architecture Models:
  - *"Fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution"* *(ISO/IEC/IEEE 42010)*
  - *"The organizational structure of a system or component; the organizational structure of a system and its implementation guidelines."* *(ISO/IEC/IEEE 24765)*
  - System models created using an ADL (Architecture Description Language) compliant tool as defined by ISO/IEC/IEEE 42010
- Behavior Models:
  - Quantitative assessments of System/Structural Plant Models. Lumped parameter models for behaviours and controls described by mathematical specifications or executable code, containing differential, algebraic and discrete equations. The application of a physics-based modelling environment.
  - Models created using MBD – (Model Based Design/Development) tools, to evaluate complex equations that are not suited or easily executed in an architecture model.

Solution Provider Categories

Definitions used in this presentation

- PLM Vendor – support for, or the ability to combine a comprehensive set of authoring tools and/or data management system(s) supporting the product development lifecycle (PLM = Product Lifecycle Management)
- ADL Vendor – seller of a standalone architecture authoring tool that is ADL compliant. ADL examples include: AADL, Acme, ARCADIA, ArchiMate, OPM, Rapide, SysML, UML. (ADL = Architecture Description Language)
- 3rd Party Vendor – seller of an integration service or software tool(s) that supports the translation, exchange, or alternative representation of models generated from two or more brands of ADL compliant authoring tools

MBSE Working Team History

Phase 1 Results

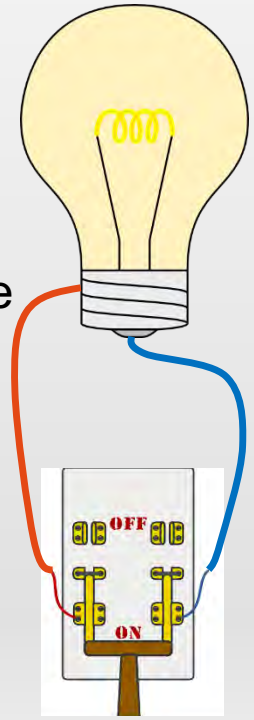
The Light Switch Example

OEM Role:

Create a simple model
Allocate requirements
Share with Supplier

Supplier Role:

Open model
Make a simple change
Resend to OEM



MBSE Data Exchange Trials		All participants prepared OEM SCD & Tecnhical Data Package; All models and Trial results data uploaded into AirCollab project folders				Red= Faliure Grey= Partial Success Green= Success	Red= Faliure Grey= Partial Success Green= Success
Round 1	**OEM Role**	**OEM Modeling Tools Used**	**Data Export Standards Used**	**Supplier Role**	**Supplier Tools Used**	**Trial Outcome (System Model)**	**Trial Outcome (Requirements)**
	Boeing	MagicDraw v18.1	UML 2.5 XMI	GE	IBM Rhapsody v8.2.1	Failure	Failure
	Boeing			Rolls-Royce	PTC Integrity v8.3.18 & Enterprise Architect, DOORS v9.5	Failure	Partial Success
	Boeing	DOORS v9.6	ReqIF v1.1	Airbus	IBM Rhapsody v8.1.4	Failure	Failure
Round 2	**OEM Role**	**OEM Modeling Tools Used**	**Data Export Standards Used**	**Supplier Role**	**Supplier Tools Used**	**Trial Outcome (System Model)**	**Trial Outcome (Requirements)**
	Airbus	IBM Rhapsody v8.1.4 (Reqs Included in SysML model)	XMI	Rolls-Royce	PTC Integrity v8.3.18 DOORS v9.5	Failure	Failure
	Airbus			GE	IBM Rhapsody v8.2.1	Failure	Failure
	Airbus			Boeing	Rhapsody 8.1.5	Failure	Partial Success
	Rolls-Royce	PTC Integrity Modeler v8.3.18	XMI	Boeing	Rhapsody 8.1.5	Failure	Failure
	Rolls-Royce			GE	IBM Rhapsody v8.2.1 DOORS NG	Failure	Partial Success
	Rolls-Royce	DOORS v9.5	ReqIF v1.0	Rolls-Royce	PTC Integrity Modeler v8.3.18	Failure	Partial Success
	GE	IBM Rhapsody v8.2.1	UML 2.3 XMI	Boeing	Rhapsody 8.1.5	Failure	Failure
	GE	DOORS NG	ReqIF v1.2	Rolls-Royce	PTC Integrity v8.3.18 DOORS v9.5	Failure	Failure

Business Opportunity Realities

Current State of A&D Industry

- DARPA, NIST, and AVSI estimate the interoperability opportunity cost to exceed > $1billion/product across the Life Cycle
- The exchange and interoperability of systems architecture models is painfully limited using the tools provided by the leading enterprise PLM/MBSE software providers.
- Without model integration, the default solution is to exchange documents defining the logical architecture, text-based requirements, and obfuscated behavior models.
- Deprived of system architecture model exchange, the industry's Digital Transformation is significantly limited with no clear path for creating the Digital Thread and Digital Twin.

Project Overview and Assumptions

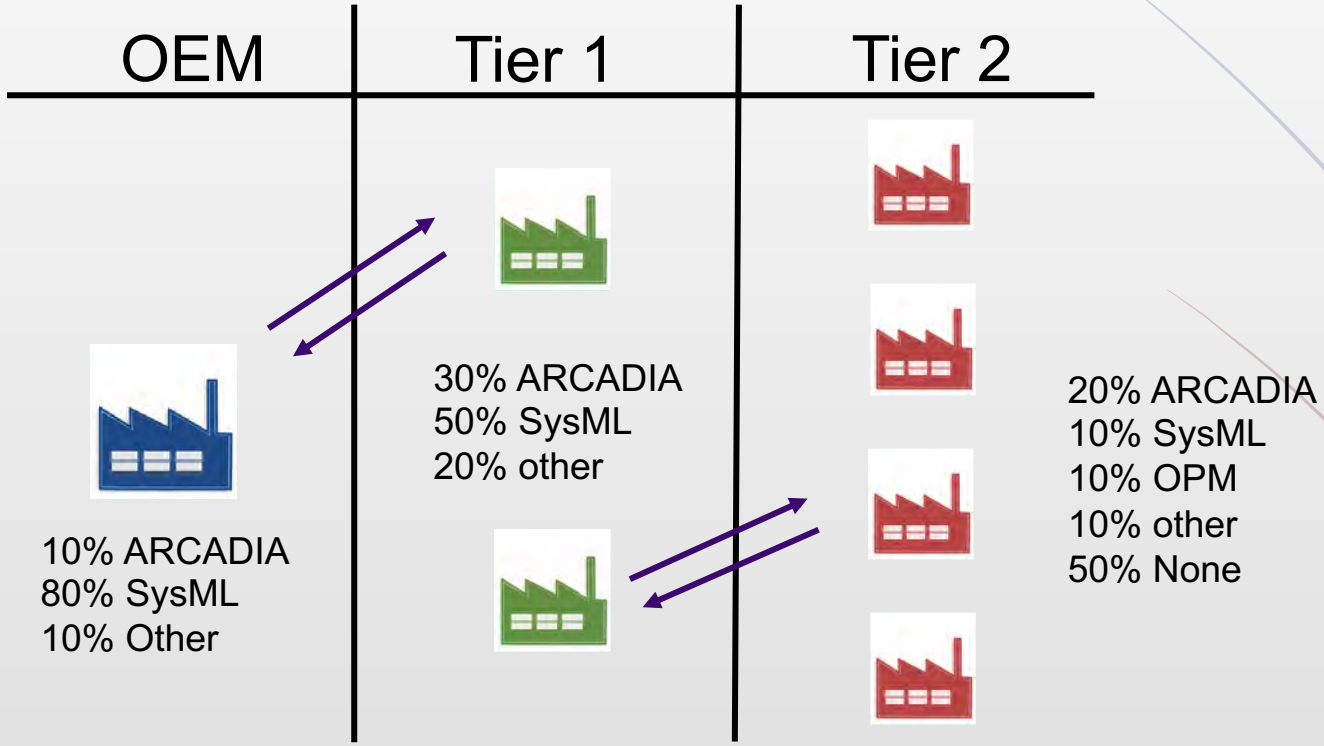
Establish a shared MBSE Vision

- The Aerospace OEMs, T1 Suppliers, and T2 Suppliers are invested in their own PLM systems and MBSE tool chains. (This assumes digital transformation is a common goal and each company's unique digital capability is a core competency.)
- The OEMs use many of the same Suppliers and unintentionally inflate their business costs by specifying specific tool brands.
- There are three basic building blocks for MBSE definition: The integration of Requirements, Behavior, and Architecture models
- Data exchange standards for Requirements and Behavior models are mature, readily available in the tools, and easily adopted. Exchanging architecture models has proven very difficult.

Challenge: OEM – Supplier Collaboration

Multiple Capabilities and Languages

Incompatible Data Flow and Modeling Capabilities

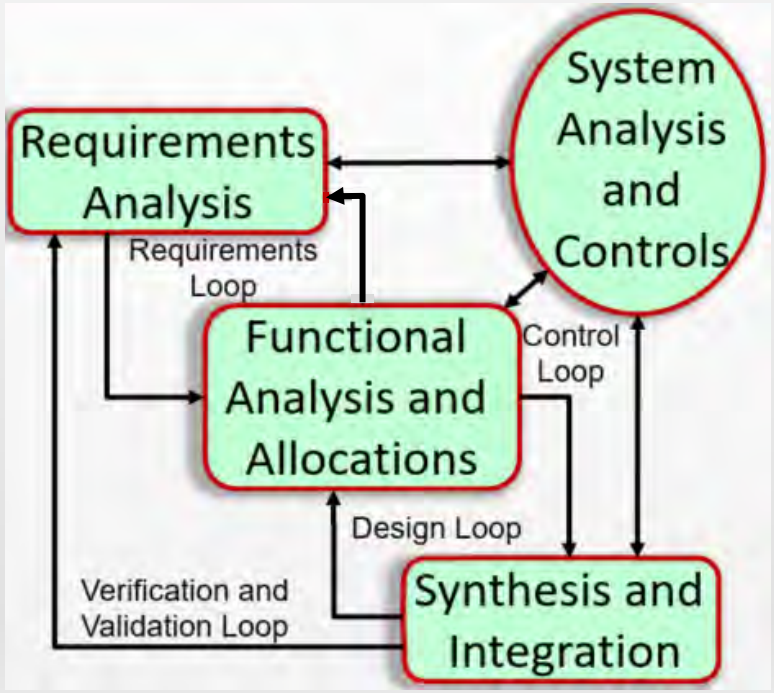
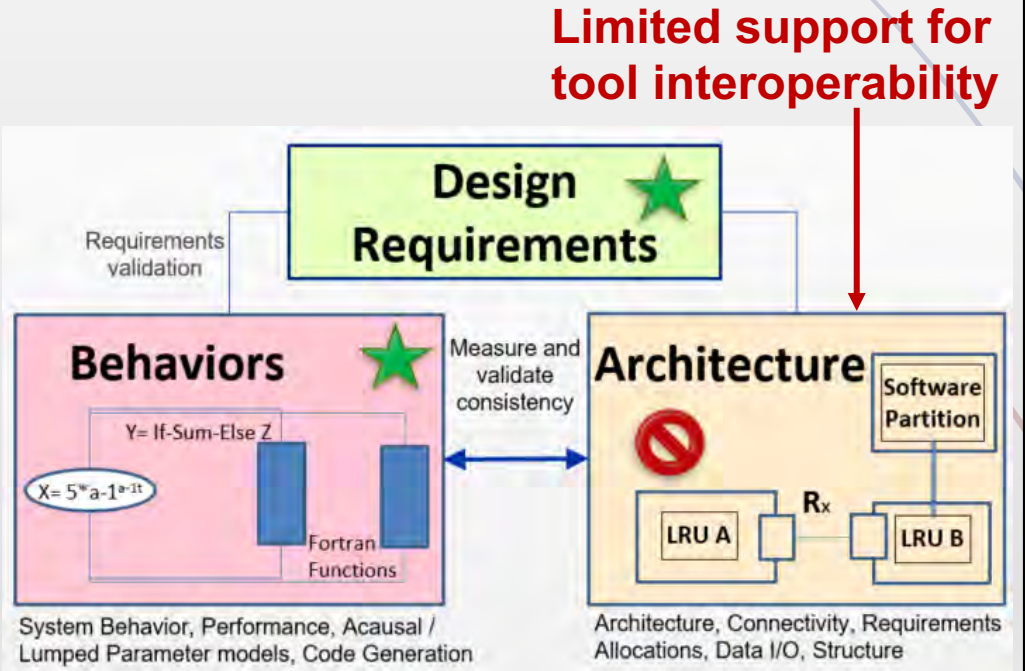


Estimated Architecture Modeling Capabilities
Tier 1 = Major technology Suppliers

MBSE Data Interoperability Specification

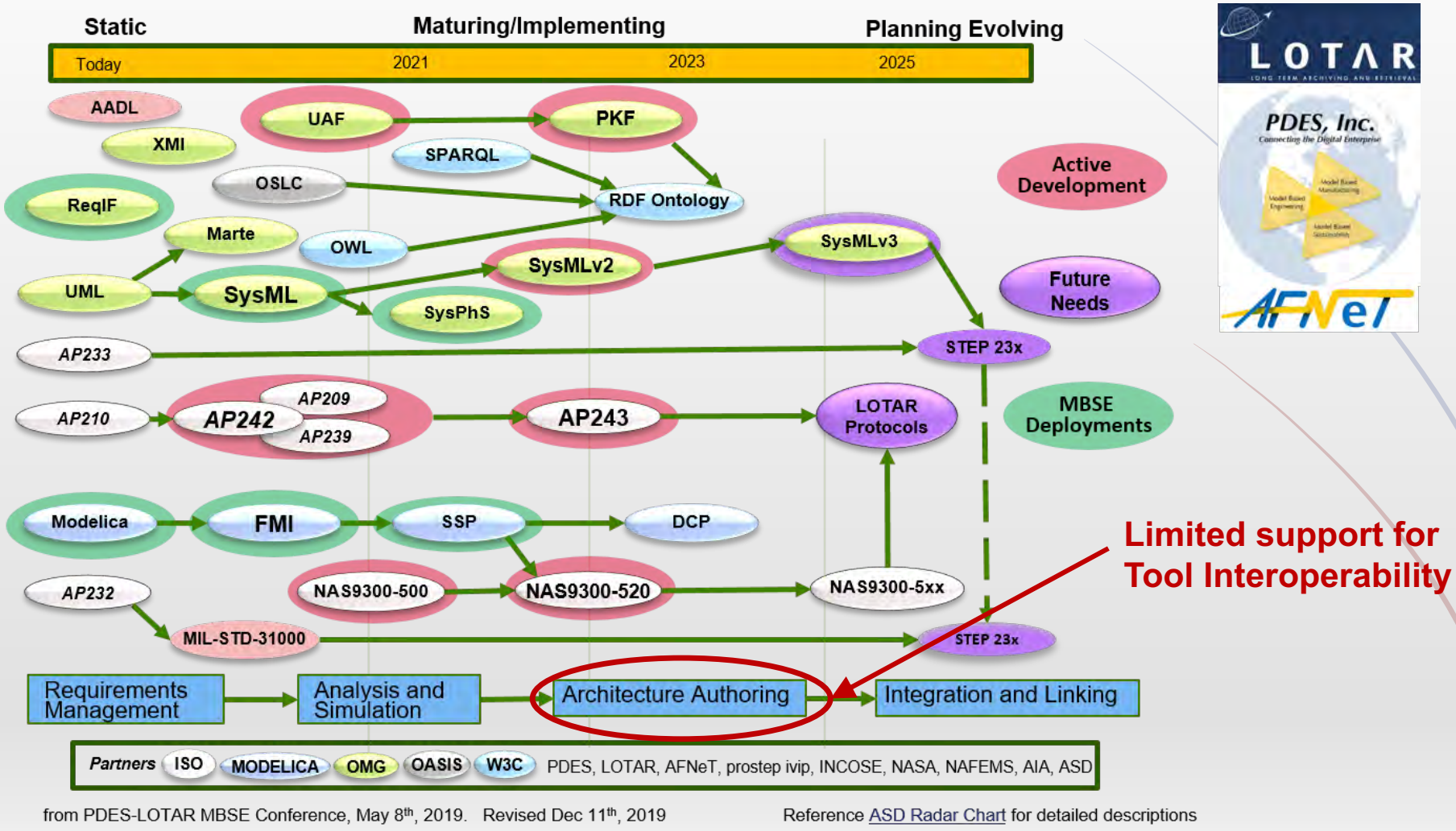
Traditional System Engineering versus MBSE Methods

Effective Exchange options for 2 out of 3 common MBSE model types

Required Capability	Model-based System Engineering
	

MBSE Data Interoperability Specification

MBSE Standards Roadmap



Initial Project Plan (Phase 3)

MBSE Data Interoperability

- Develop process driven Use Case specifications for MBSE model exchange to enable OEM/supply chain design collaboration
- Extend the Use Cases to include all system architecture model interface needs including how to map the language alternatives
- Evaluate interoperability: Tool vendor capabilities with respect to the use case requirements, and definition of maturity scores for the 3rd party tools

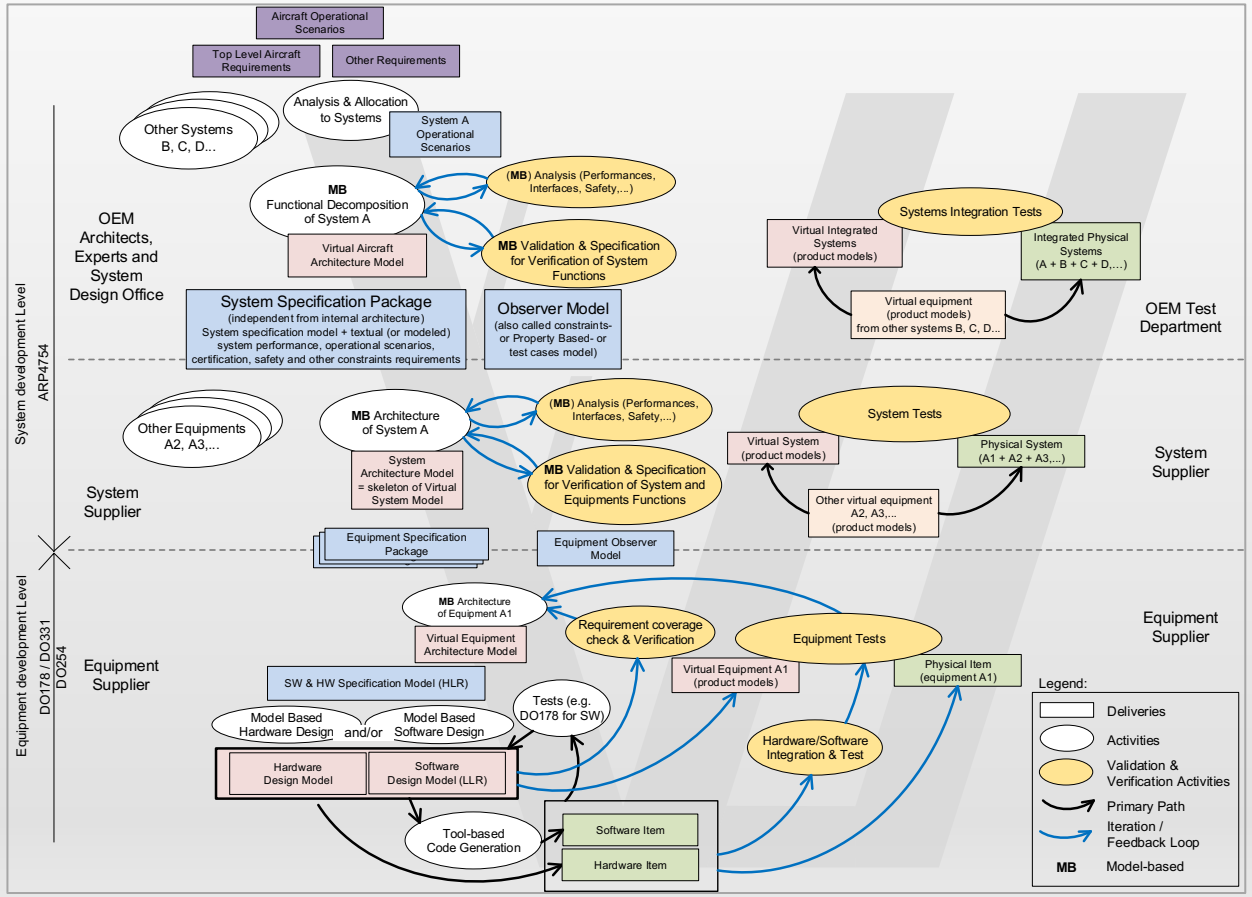
Methods of Data Exchange

Definitions and Levels of Implementation Maturity

- Traditional – Transmit and receive documents and images. Use graphs, tables and descriptions to summarize modelling results.
- Model Exchange – Usually defined as contractual requirement. A one-way transmission of specific content. (Prevalent for sharing 3D CAD content, and limited capability for other model types.)
- Interoperability – Models are exchanged, edited, and re-shared between companies. Assumes that multiple versions may exist. (several examples in aerospace, but common in automotive industry by enforcement of common tools)
- Collaboration – One model version is maintained as master and accessible to both companies. (Marketing vision of PLM vendors, but branding issues imply mature data standards are basis of model creation)

MBSE Data Interoperability Specification

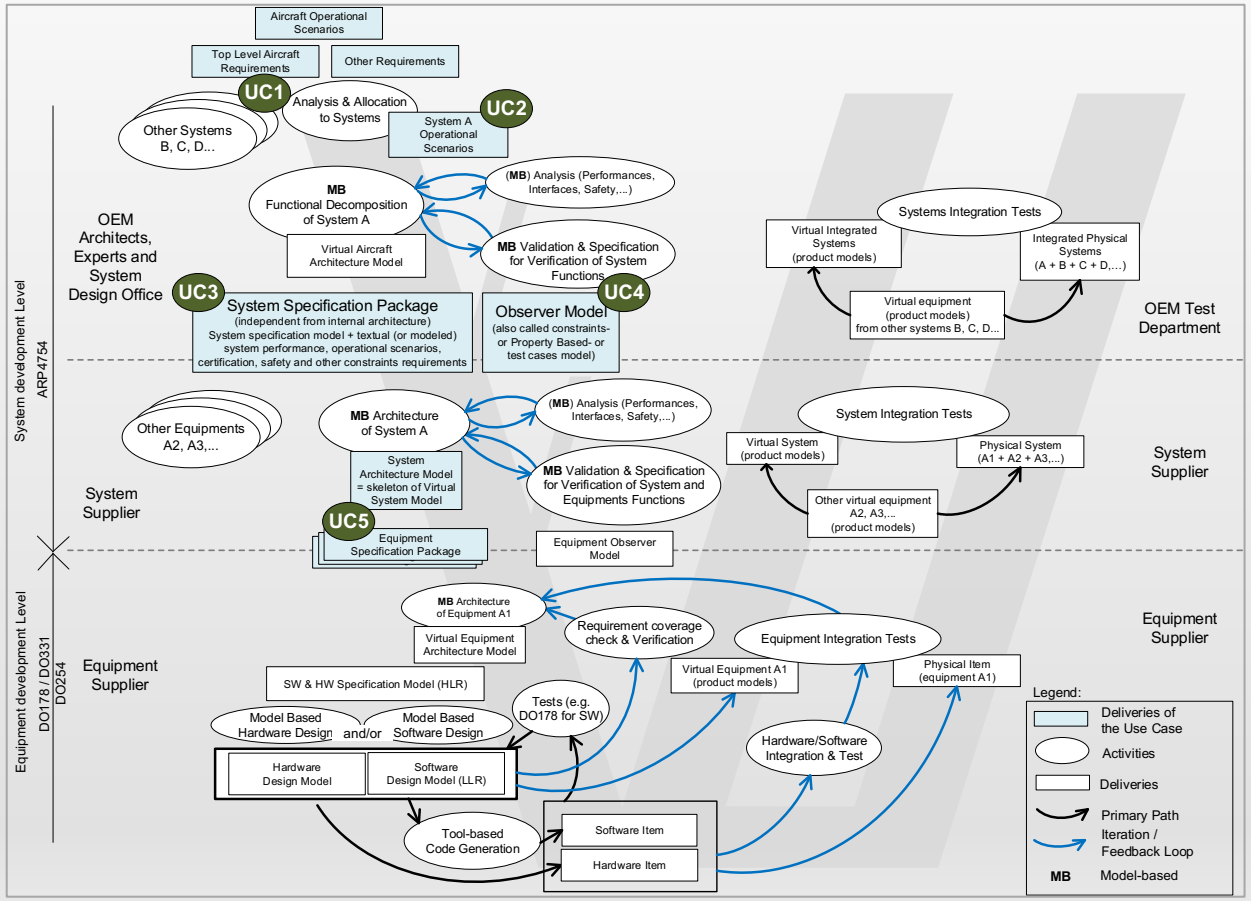
Correlation of Traditional Process Lifecycle with MBSE Use Cases Project



- The specification of dedicated use cases for an overall MBSE process requires input and agreement from the primary stakeholders. This figure describes the overall MBSE process mapped to the classical systems engineering “V” as the baseline for the use case definitions.
- The system development lifecycle process consists of three basic activities
  - Specifying and designing the system itself
  - Verifying and validating that system design
  - Managing the overall development project

MBSE Data Interoperability Specification

Identify Use Cases in need of Data Exchange



- The initial process can be divided into three phases: the conceptual phase, the preliminary design phase, and the detailed design phase.
- To identify the deliverables of the different steps within the overall process, the following use cases that describe the activities and deliverables in a top-down process are identified:
  - Use Case 1: System of Systems and Transitioning the Functional Interfaces to Logical Systems
  - Use Case 2: Define System Operational Scenarios
  - Use Case 3: Export System Functional Specifications
  - Use Case 4: How the Functional Specification and supplier product will be Validated (define the system context)
  - Use Case 5: Export Hardware/Software Functional Specifications

MBSE Data Interoperability Specification

Modeling Language Options

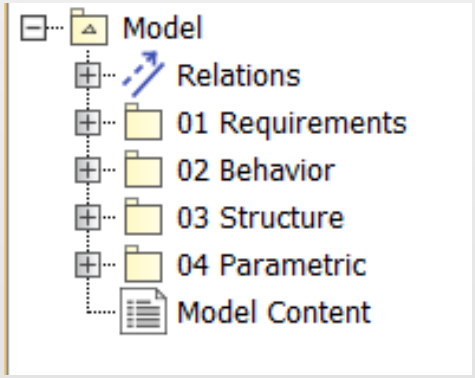
- SysML (v1.6) is the most popular industry wide MBSE architecture modeling language
- However, implementations of the ARCADIA methodology have grown rapidly (the 'Capella' authoring tool was developed and open sourced by Thales in 2015)
  - Supports hierarchical architectural decomposition of complex systems
  - Particularly suited for large complex mechanical systems where emergent behavior is prevalent (unconstrained by OO principles of Encapsulation, Aggregation and Composition)
  - Open source – Extensible, no cost extension of Papyrus UML. No proprietary API (XMI) - low/zero barrier to integration with other toolsets.
  - Adoption by leading PLM tool vendor(s)
- ARCADIA (Capella) has therefore been included in this MBSE interoperability study
- We also recognize that Office Automation Tools (e.g. Microsoft/Open Office) prevail as the de facto standard for creating design specifications

MBSE Data Interoperability Specification

Language Compatibility

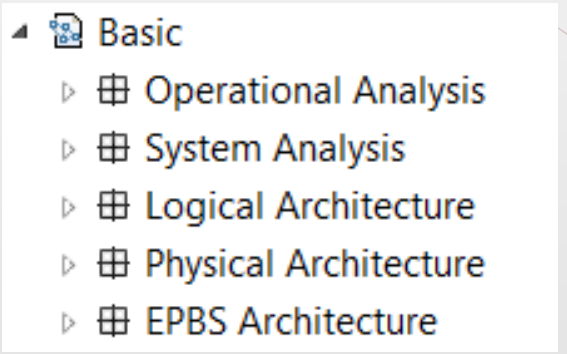
- For Use Case 3, an agreed modelling standard will be required to enforce consistency and enable model data exchange (assumes SysML <–> ARCADIA, or SysML <–> SysML)
- For SysML <–> ARCADIA model data exchange requires a mapping of views and elements:

SysML



The Package structure in SysML is defined by the user and could be completely different between models.

ARCADIA



The Capella tool enforces the ARCADIA methodology as a framework. This means consistency across all Capella models.

MBSE Data Interoperability Specification

Model Mapping

SysML <–> ARCADIA model data exchange

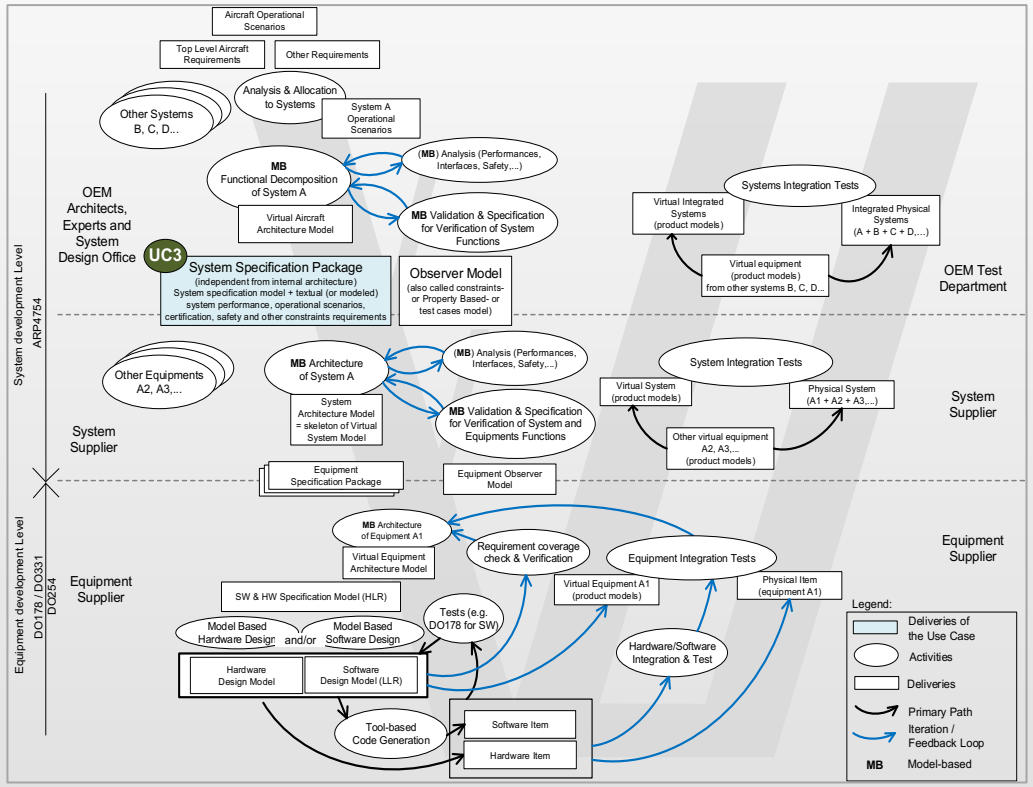
- A comprehensive mapping between SysML and ARCADIA (diagrams, model elements and relationships) defined for all the artifacts identified in Use Case 3 (partial table extract)
- OEM and Supplier model data exchange for Use Case 3 can be based on this mapping

ARCADIA			SysML		
Diagrams	Model Elements	Relationships	Diagram	Model Elements	Relationships
(SA) Mission/Capability			Use Case		
	Capability			Use Case	
	Actor			Actor	
	Component			Block	
		Involved			Association
		Extends			Extends
		Includes			Includes
(SA) Architecture			Block Definition		
	Component			Block	
	Properties			Properties	
		Contained In			Generalization
		Contained In			Composition
		Contained In			Aggregation
(SA) Architecture			Internal Block		
	Component			Block Part	
	Port			Port	
		Exchange(Funct,Comp, Phys)			Connectors
		Exchange(Funct,Comp, Phys)			Item Flows
(SA) Functional Breakdown			Activity		
	Function			Action	
	Ports			Port	
	Control Node			Control Node	
		Functional Exchange			Flow
		Functional Exchange			Control
		Functional Exchange			Object Flow

Summary Example

MBSE Data Interoperability Specification

Data Exchange Criteria for Priority Use Case 3 & 4



Use Case 3 - Export System Functional Specifications

The first important Use Cases because it represents the Buy-Package interface between the OEM and the supplier. The drivers behind the exchange of architecture models include:

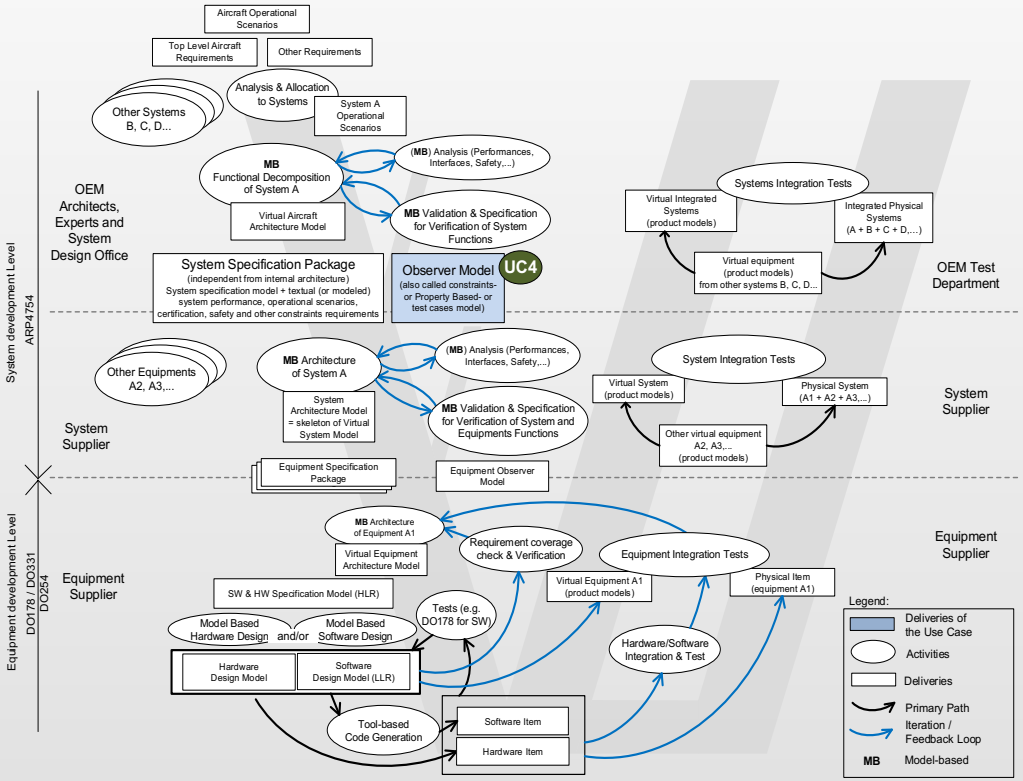
- collaboration on the contents of a Buy-Package
- common understanding of the model syntax
- model reuse at supplier side

The minimum set of diagrams and languages needed to represent the system specification artifacts for Use Case 3.

ARCADIA	SysML
Component Breakdown diagram	Block Definition diagram
Component Interface diagram	Internal Block definition diagram
Architecture diagrams	Activity diagram
Functional Data Flow diagram	Sequence diagram
Functional Scenario diagram	

MBSE Data Interoperability Specification

Data Exchange Criteria for Priority Use Cases 3 & 4



Use Case 4 - Validating the Supplier Models

The second important Use Cases because it supports the system functional validation at OEM and the supplier side. The drivers behind the exchange of V&V models include:

- a common understanding of the system context
- validation of functional specification completeness
- model reuse at supplier side for product validation before delivery

The minimum set of diagrams and languages needed to represent the observer model:

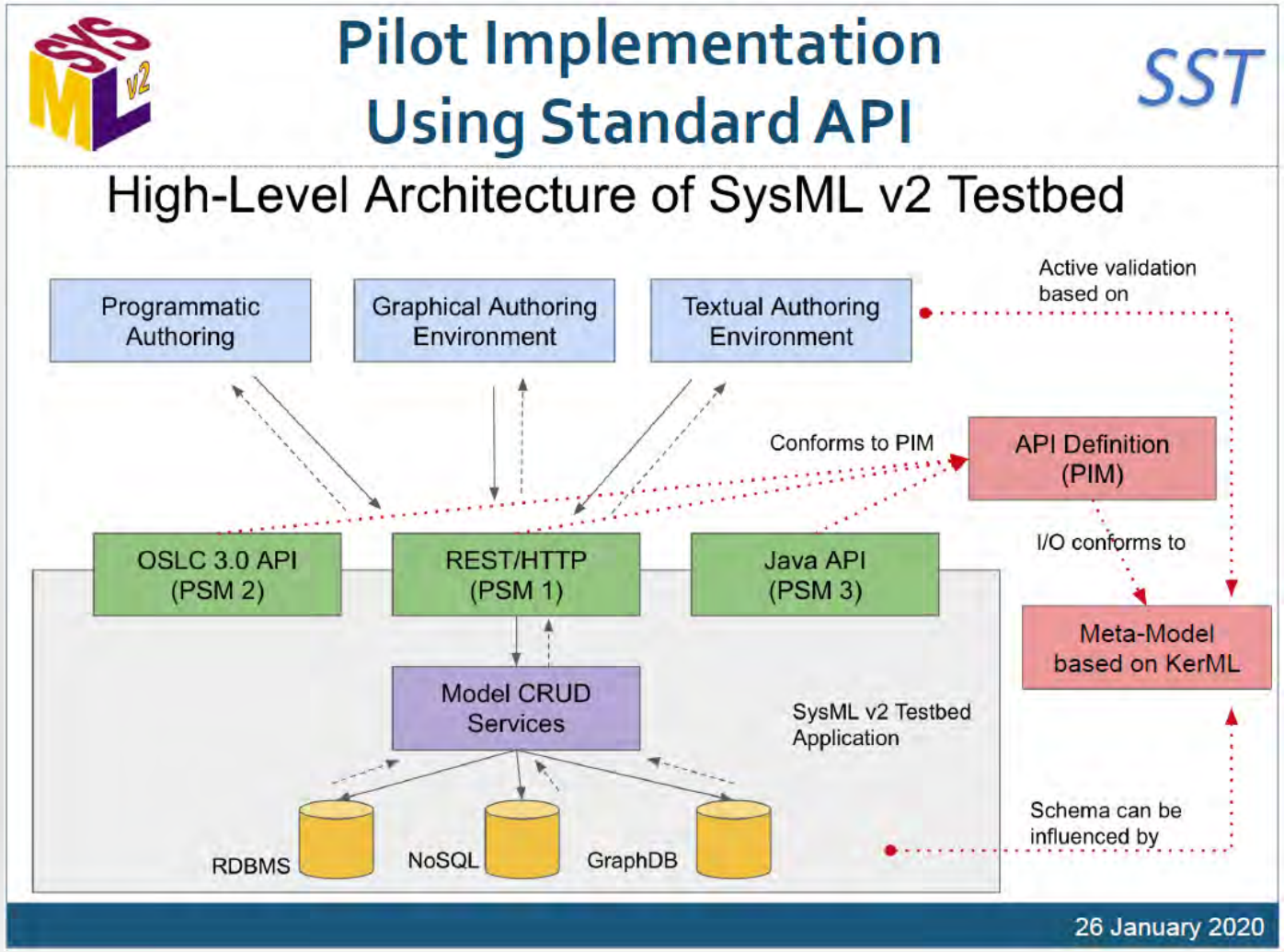
ARCADIA	SysML
Entity/Functional Scenario diagrams	Sequence diagram
Logical/Physical Architecture diagrams (Parametric viewpoint)	Parametric diagrams
Mode/State diagram	State diagrams

Future Business Challenges

ADL Data Exchange

- Point to point model data translation (SysML <–> ARCADIA or SysML <–> SysML), is possible, however:
  - A model translation capability based on the current SysML standard (v1.6) is not a long-term solution, but an interim capability could be cost effective.
  - SysML v2.0 is a paradigm shift from the current SysML standard (v1.6)
  - SysML v2.0 will offer multiple data interoperability options. We assume at least two years before the industry deploys the first initial alternatives.
- The SysMLv2 solution does not guarantee data exchange. The specification options include exposing an API, RESTful services, or OSLC support for a “data linking” solution.
- We are aware of at least three MBSE tool vendors that expose their API and two that demonstrate reasonable exchange success. (API = application programming interface)

SysML V2 – Interoperability Options



Sandy Friedenthal
INCOSE
IW2020 presentation

MBSE Data Interoperability Alternatives

Explore 3rd Party Vendor Capabilities

Paper Analysis of potential solutions

- Evaluated 12 products comprising 2 categories of capability
  (categories include a point2point translation or an integrating database)
- No dominant COTS solution with expected functionality
- No easy path to Benchmark and Validate Use Cases
- No common business case between project team members

		Experienced ADL Exchange Companies/Tools			Engineering Services	
Companies			Company1	Company2	Company3	Company11	Company22
Products			Product1	Product2	Product3	Product1	Product2
CRITERIA	*weight*	*describe criteria*					
Language							
SysML	1000	target language	100%	100%	100%	50%	Custom Service
Max score:	43100	Total score:	23000	19500	800	14500	21000
		Percentage of maximum score:	52.00%	45.00%	18.00%	33.00%	48.00%
		How many criteria scored:	54	60	21	47	62

Summary Example

MBSE Data Interoperability – Summary

Final Phase 3 Deliverables

- Created multiple Use Cases defining the specifications for process driven model exchange across the lifecycle
- Generated a definition of the primary MBSE artifacts (diagrams) to be exchanged between the OEM and Supplier (Use Case 3), and how they will be validated (Use Case 4)
- Developed a comprehensive mapping between SysML and ARCADIA (diagrams, model elements and relationships)
- Conducted an evaluation and scoring of language specific tool capabilities with respect to the use case requirements
- Initiated white paper to capture results

MBSE Data Interoperability – Alternatives

Possible MITIGATIONS

- The Aerospace community is aligned on interoperability standards for bi-directional model exchange and real time collaboration.
- Establish an Implementer's Forum to validate the data exchange Use Cases and assess the overall capabilities of the individual ADL product brands.
- The products from 3rd party vendors rely on each tool's exposed API. Engage and encourage the ADL vendors to expose their APIs.
- In the interim, without a common model exchange methodology, focus on translation services from either the individual PLM tool vendors or 3rd party software vendors.

MBSE Data Interoperability – Issues

Common Issues

- The implementation of MBSE data standards is not consistent. This impacts the stability, compatibility, compliance and long term choice of any specific vendor's authoring tool.
- What priority each company assigns to MBSE modeling and data standards development
- How to assess the accuracy and completeness of a translation
- How to manage IP protection during model exchange and translation
- How to trade the labor + translation tool costs against the value of the exchange capability
- A tool vendor's on-going support for functionality used by a 3rd party translation service
- How to protect Enterprise tool investments that are impacted by changes to the exchange standards, advances in digital technologies, and redundant spending

Our Communication Summary

- The Problem Statement solution cost is high, but the costs for no solution are potentially greater. The PLM vendors have not defined alternatives. Adding the impact of COVID virus, additional delays will stall new investments and the industry's recovery.
- Waiting for SysMLv2 will defer the value of our PLM implementations and our industry's digital transformation. Achieving interoperability with the assistance of a 3rd party vendor represents our recommended interim strategy.
- Maintain our focus on the MBSE interoperability standards: Canonical XMI, MoSSEC, ReqIF, FMI, LOTAR, and APIs for architecture models and graphics.

MBSE Data Interoperability – Next Steps

MBSE Working Team Focus Areas

- Release the Phase 3 position paper
- Define requirements for a model exchange protocol and a generic modelling interface with respect to any vendor's tool
- Establish the testing - validation criteria needed to qualify a 3rd party solution, and define the benefits of adoption (leverage other industry initiatives)
- Utilize the MBE Demonstrator RM to establish a test environment, share our findings, and solicit industry feedback

(*Multiple standard bodies sponsor the Model-based Engineering Demonstrator and Reference Models. It is a GitHub repository in the public domain dedicated to sharing domain specific models and process data.)*