Model-Based Systems Engineering

2025 Market & Industry Forum—10 April 2025

Model-Based Systems Engineering

2025 Market & Industry Forum—10 April 2025

Key Takeaways

Model-Based Systems Engineering (MBSE)

- Systems engineering is evolving from paper-based processes to the use of digital artifacts that can be continuously updated and managed
- MBSE adoption is still in early stages in many industry segments with aerospace & defense, infrastructure, and high-tech leading the way
- MBSE focus today is in concept design and development phase but there are applications emerging in downstream lifecycle stages
- Linking higher fidelity physics-based modeling, simulation and AI with requirements and architecture models will accelerate MBSE adoption
- Open platforms & data/model interoperability are key to success

3

Systems Engineering in Practice

Key functional aspects of executing a formal systems engineering process (1 of 2)

- ***Requirements Analysis***—understanding VoC/stakeholder needs & translating them into system requirements that are then decomposed into sub-system, component & domain specific requirements
- ***System Architecture Design***—defining the system's functional, logical & physical structure, i.e., identify key components and interfaces while accounting for the interaction of multiple product engineering domains (mechanical, electrical/electronics, embedded software/controls, IT networks, chemical, manufacturing, supply chain, in service operations, etc.). that are required to meet the system design objectives
- ***Trade Studies***—use DoE & robust design modeling & simulation tools to simulate the system behavior & optimize the system design characteristics across the feasible design envelope

4

Systems Engineering in Practice

CIMdata

Key functional aspects of executing a formal systems engineering process (2 of 2)

- ***Quality Engineering***—leverage QFD, AQPQ, FMEA & Six Sigma methodologies
- ***Risk Assessment***—safety & reliability analysis
- ***Verification & Validation***—ensure that the system meets its intended purpose and performance goals
- ***Lifecycle Management***—managing & sharing of the system design IP (data, metadata, models, documents) and standard processes associated with the above key aspects of the system design throughout its entire lifecycle…traceability of information is essential

5

Systems Engineering in Practice

CIMdata

A core value driver for the digital thread: starting the model-based engineering process

Systems Engineer

The systems engineer should develop the skill for identifying and focusing efforts on assessments to ***optimize*** the overall design and not favor one system/subsystem at the expense of another while constantly ***validating*** that the goals of the operational system will be met.

Source: NASA Systems Engineering Handbook

Optimization

Finding an alternative with the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones.

Source: BusinessDictionary.com

Validation

Showing that the product accomplishes the intended purpose in the intended environment—that it meets the expectations of the customer and other stakeholders as shown through performance of a test, analysis, inspection, or demonstration.

Source: NASA Systems Engineering Handbook

6

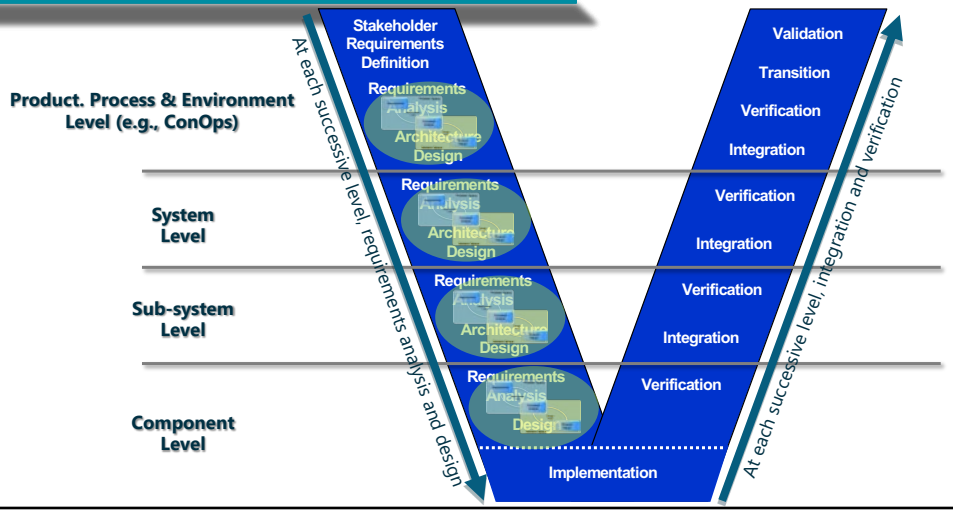
Model-Based Systems Engineering

2025 Market & Industry Forum—10 April 2025

Systems Engineering in Practice

CIMdata

Design processes repeat at each level of the system hierarchy



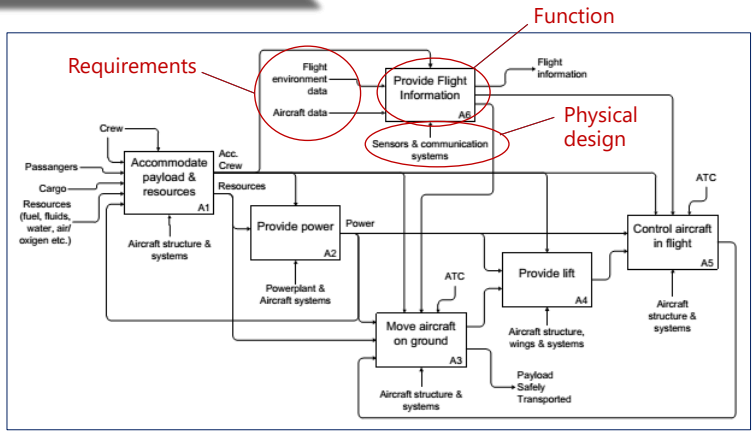
Systems Engineering in Practice

CIMdata

Why is "Functional" analysis key?

The functional model is the link between requirements & physical design:

Will the system perform as intended and meet the stated requirements of the end customer, as well as all stakeholders involved?



Source: G. Esdras and S. Liscouët-Hanke, Bombardier Product Development Engineering, Aerospace, Montréal QC,~2014

Model-Based Systems Engineering

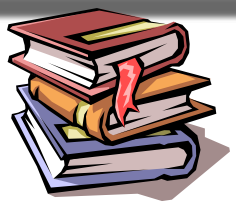
2025 Market & Industry Forum—10 April 2025

Model-Based Systems Engineering

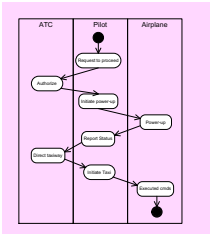
CIMdata

Moving from documents to models. Objective: "A robust authoritative source of truth"

Past



- **Specifications**
- **Interface requirements**
- **System design**
- **Analysis & Trade-off**
- **Test plans**



Future

Moving from Document-centric to Model-centric

9

Source: INCOSE http://www.incose.org/

Model-Based Systems Engineering

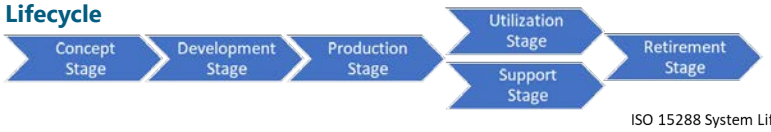
CIMdata

Moving from documents to models with all of the benefits & challenges that implies

Model-based systems engineering (MBSE) is the ***formalized application of modeling*** to support system ***requirements, design, analysis, verification and validation*** activities beginning in the conceptual design phase and continuing ***throughout development and later lifecycle phases***.

And the ***system of interest*** can be the ***product***, ***production*** or ***support*** system

System Lifecycle



ISO 15288 System Lifecycle

10

Source: INCOSE

Model-Based Systems Engineering

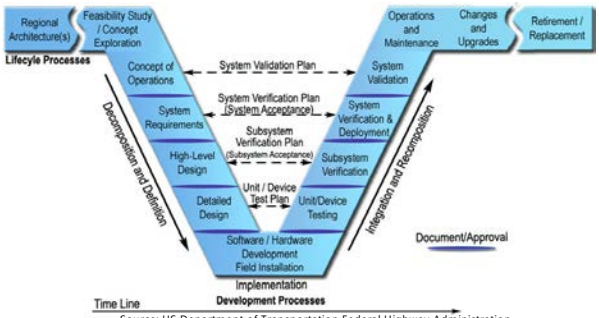
2025 Market & Industry Forum—10 April 2025

Moving Toward a Model-Based Future

CIMdata

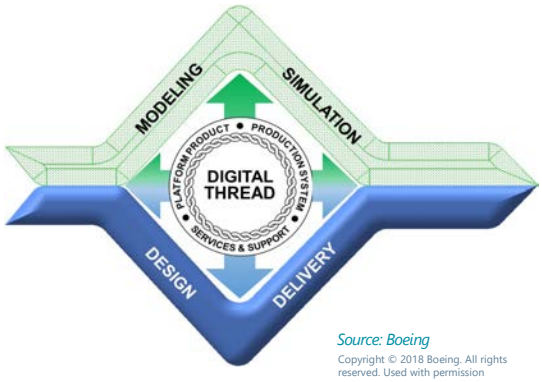
Moving from documents to models: "A verifiable source of truth"

SE Vee



Source: US Department of Transportation Federal Highway Administration
https://ops.fhwa.dot.gov/publications/seitsguide/section3.htm

MBE Diamond



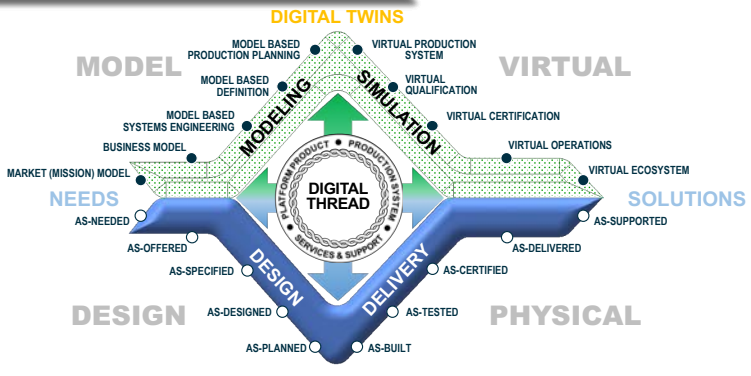
Source: Boeing

Transitioning from a document-focused mindset to a digital engineering mindset that leverages information flows across the lifecycle

Moving Toward a Model-Based Future

CIMdata

Modeling & simulation is a core strategic element in transitioning to a digital thread



Source: Boeing

Digital & Physical Twins joined by a digital thread that supports change at all stages of the lifecycle

Model-Based Systems Engineering

2025 Market & Industry Forum—10 April 2025

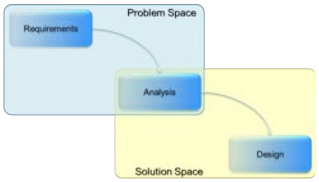
Model-Based Systems Engineering

CIMdata

MBSE methods maturity: an evolving level of modeling & simulation "in the loop" (1 of 2)

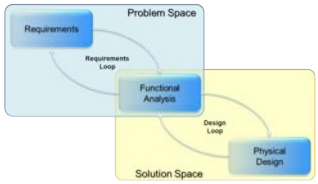
Level 1 – Requirements analysis & design

"Optimization" in the judgement of a good designer



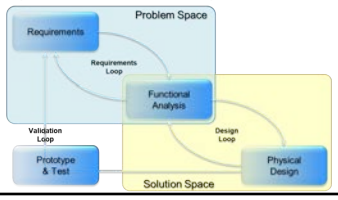
Level 2 – Modeling & simulation

Simulation and trade studies to support requirements analysis and design alternatives evaluation



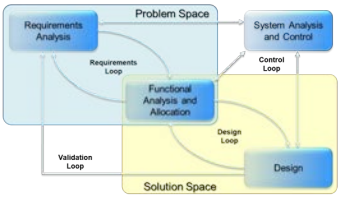
Level 3 – Modeling & simulation with physical validation

Simulation and trade studies to support requirements analysis and design alternatives evaluation, and testing for validation and certification



Level 4 – Modeling & simulation with virtual validation

Application of modeling to support system requirements, design, analysis, verification and validation



13

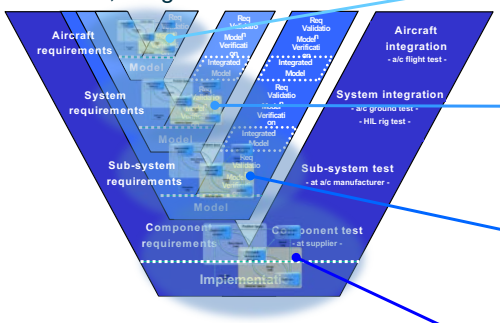
Model-Based Systems Engineering

CIMdata

MBSE methods maturity: an evolving level of modeling & simulation "in the loop" (2 of 2)

Level 5 – Automated modeling, simulation, validation

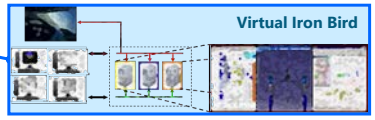
Continuous analysis, allocation, design, verification, integration and validation



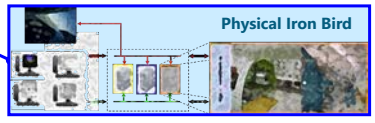
MIL: Model-In-the-Loop simulation
SIL: Software-In-the-Loop simulation
PIL: Processor-In-the-Loop simulation
HIL: Hardware-In-the-Loop simulation

MIL

MIL + SIL + PIL



MIL + SIL + PIL



MIL + SIL + PIL + HIL

14

Model-Based Systems Engineering

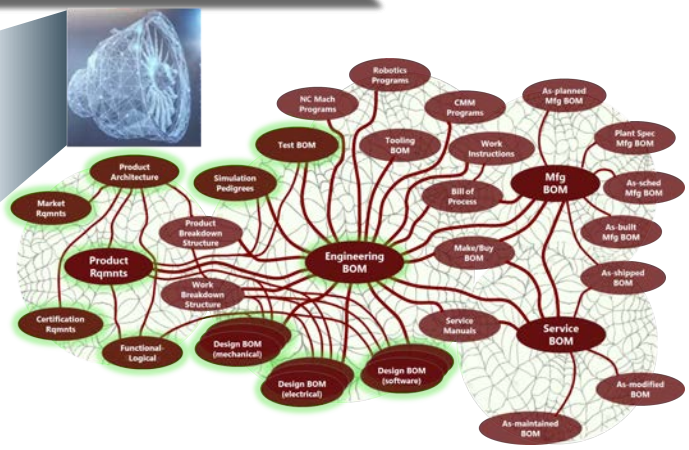
2025 Market & Industry Forum—10 April 2025

MBSE & the Digital Twin

CIMdata

The MBSE digital thread links the artifacts that compose the digital twin

- Requirements
- Functional structure
- Behavior models
- Product structure
- Mechanical models
- Electrical models
- Software models
- Engineering BoM
- Simulation pedigrees
- Test BoM
- . . .



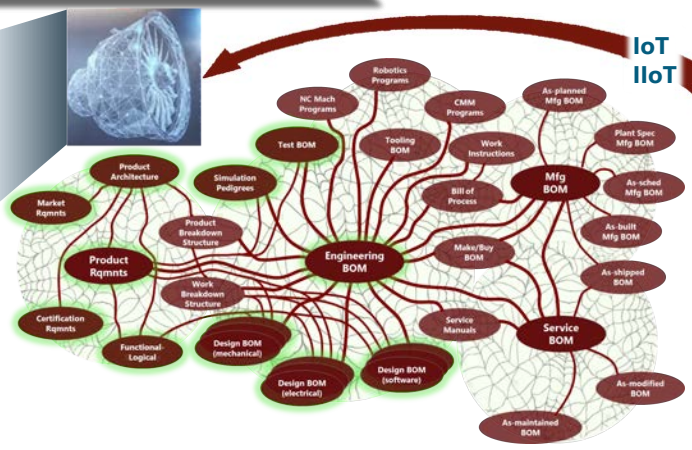
15

MBSE & IoT/IIoT

CIMdata

Closing the loop in real-time between field performance and the performance models

- Requirements
- Functional structure
- Behavior models
- Product structure
- Mechanical models
- Electrical models
- Software models
- Engineering BoM
- Simulation pedigrees
- Test BoM
- *Mfg perf model*
- *Operation perf model*
- *Service perf model*



Real-time optimization of manufacturing, operation, and service

Leveraging AI/ML, training the LLMs for insight

16

MBSE Trends: Addressing the Challenges

CIMdata

How is the engineering software and solutions market responding?

- Product Innovation Platforms (a "Platform of Platforms")
  - Link MBSE with ALM + PLM + S&A + MCAD + EDA + IoT/IIoT + Others (e.g., ERP & SLM)
- Integration of underleveraged M&S and SPDM tools with SE tools
- MBSE data exchange & model interoperability standards to enable the lifecycle digital thread and associated digital twins
- Leveraging emerging AI/ML technologies for "augmented intelligence" and "democratization" of an MBSE approach

17

MBSE Status: Varies Widely

CIMdata

Multiple factors have and will continue to have impact on the adoption of MBSE

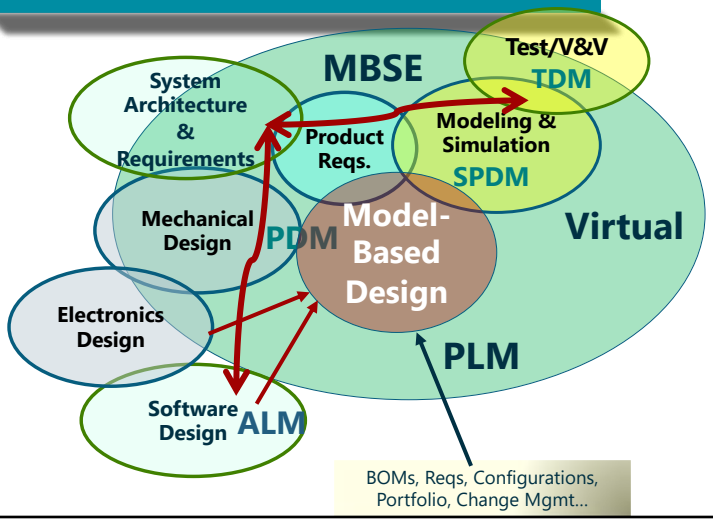
- MBSE is gaining traction in multiple industries due to factors such as increasing product complexity, and the growing role of software in products
- While the foundations for MBSE was primarily led in the A&D industry, the automotive industry, by many accounts, has accelerated past the A&D industry due the significant increase in software content
- Like other new ways of working, organizational impact & cultural resistance pose the most significant challenge MBSE's success
- The role of standards will continue to play a major role in enablement

18

Starting the MBSE Digital Thread ("The Challenge")

CIMdata

Conceptual SE across domains with linkage to PLM/M&S for trade studies/V&V



MBSE – Primary Use Case today:
Conceptual Design, Optimization and Validation Of Cyber-Physical Systems

The digital thread needs to connect information across domains:

* Systems Arch. & Requirements
* Software/ALM
* EDA/ECAD/EBOM
* MDA/MCAD/PDM
* M&S/CAE/SPDM
* Test/V&V/TDM

19

Digital Engineering Driving "Platformization"

CIMdata

Industry leaders investing to enable MBSE for digital thread/web and digital twins

PLM Market Leaders: Extending across Engineering Domains — March 2025

Engineering Domain	Synopsys/ ANSYS	Siemens DI/ Altair	Dassault Systèmes	Hexagon/MSC Software	Cadence/ BetaCAE	Keysight/ESI	Autodesk	MathWorks
Requirements Authoring, Allocation & Requirements Management		X	X					
MBSE/System Architecture Design	X	X	X					X
Software Engineering- Embedded & Controls	X	X	X	X		X		X
Electronics Systems Design & Analysis	X	X			X	X		
Multi-Physics Simulations, System Analysis and Synthesis	X	X	X	X	X	X	X	X
IoT Platform/Data Analytics	X	X	X	X	X	X	X	X
Chemical Engineering Analysis	X	X	X					
AEC Industry- Structural Analysis & Design Code Certification		X					X	

20

Model-Based Systems Engineering

2025 Market & Industry Forum—10 April 2025

Simulation & Analysis (S&A)

CIMdata

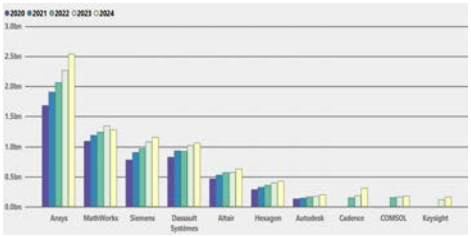
Drive to provide integrated platform of solutions across S&A now expanding into EDA

Revenues presented are CIMdata estimates

Year	Revenue	YoY	5 Year CAGR
2023	$10,031	8.7%	-
2024	$10,910	8.8%	10.3%

Revenues in $US millions

S&A Segment Leaders



Comments on the Segment

- Trends driving growth will remain strong (smart connected products, Industry 4.0/5.0, Need for more robust multi-domain simulation on the left side of the Vee (MBSE); Rapidly growing impact of data analytics and AI/ML
- Platforms and data interoperability growing in importance
- Growing systems complexity driving need for multi-physics, multi-scale and multi-domain modeling and simulation including physics-based digital twins across the entire product lifecycle
- MBSE, S&A and EDA solutions intersection is growing

S&A consolidation continues: Notable M&A

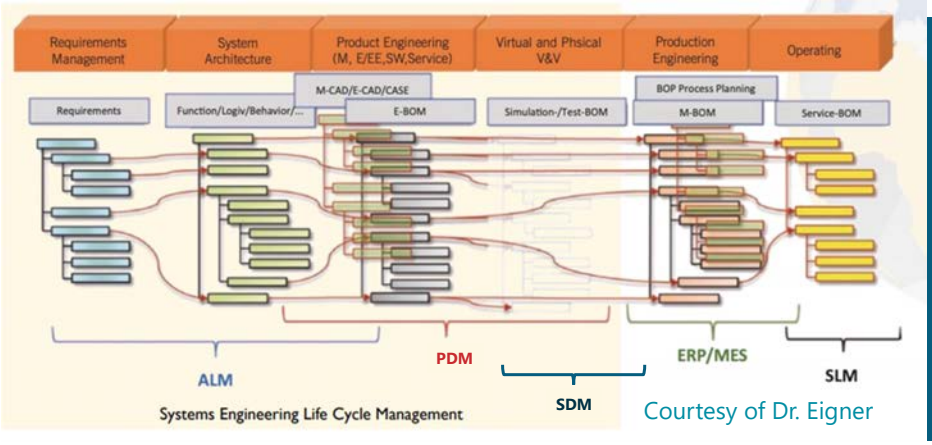
- *Keysight acquisition of ESI completed in 2024 and purchase of Optics/Photonics/Semiconductor business from Synopsys/Ansys is ongoing (deal pending approvals)*
- *Ansys being acquired by Synopsys (deal pending approval)*
- *Cadence completed acquisition of BETA CAE in 2024*
- *Siemens acquisition of Altair (deal pending approval)*
- *Several smaller "tuck in" acquisitions have also occurred*

21

Complex Products – Where to Manage?

CIMdata

Domain silos must integrate well, starting with a single, clear, and complete language



Courtesy of Dr. Eigner

Effective collaboration needs a clear language!

22

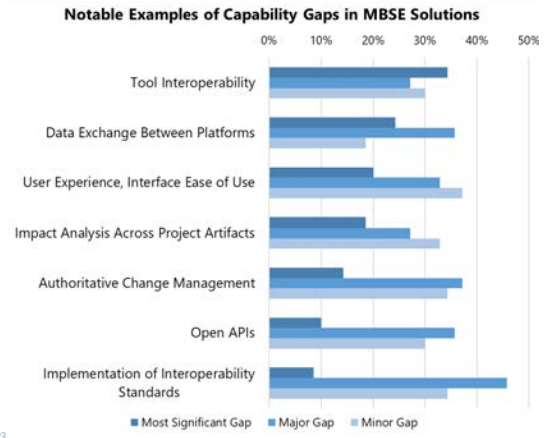
Model-Based Systems Engineering

2025 Market & Industry Forum—10 April 2025

MBSE Survey: Technology Considerations

CIMdata

Notable examples of capability gaps in current COTS MBSE solutions



(% of survey respondents)

- Notable gaps in technology to enable MBSE are all focused on data/model interoperability
- Standards and open APIs for data authoring tools figure prominently in the results from the survey respondents

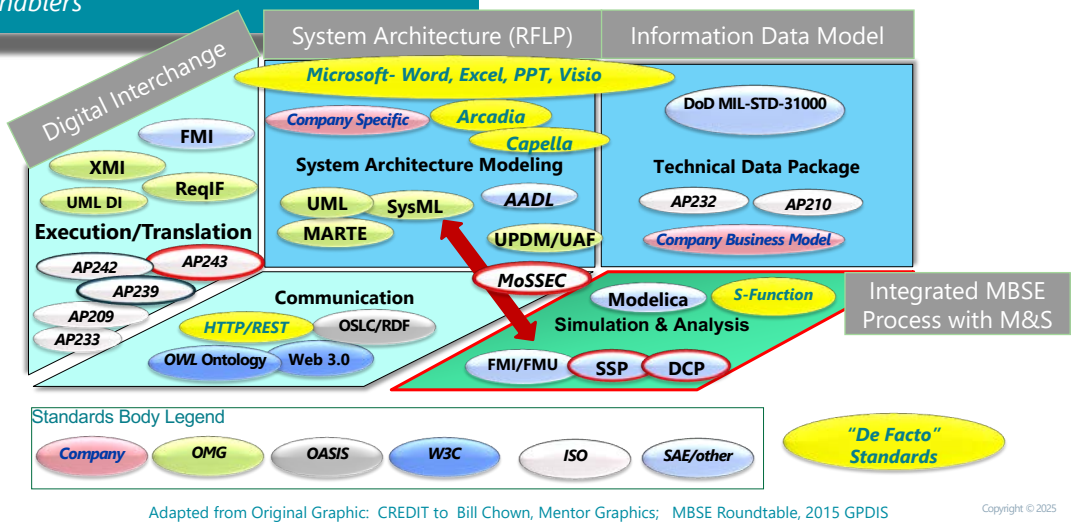
Source: ADPAG MBSE Research Report of Findings, December 2024

High Impact "Standards"

CIMdata

MBSE process & data interoperability enablers

Combination of formal international standards & industry "de facto" standards will enable MBSE



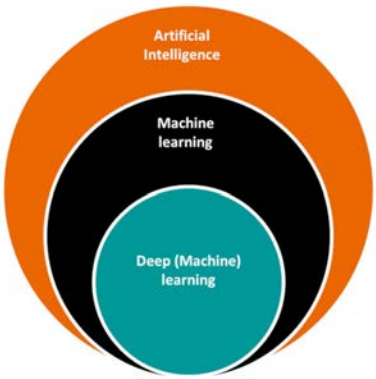
Adapted from Original Graphic: CREDIT to Bill Chown, Mentor Graphics; MBSE Roundtable, 2015 GPDIS

Opportunities: Addressing MBSE Challenges

Leverage AI/ML/deep learning and VR/AR to accelerate PLM, M&S, and MBSE processes

MBSE application areas to augment human decision making and "democratize" usage:

- Interactive task specific User Interaction (UI) & "AI Agents"
- Leverage IIoT/data analytics with physics-based Digital Twins
- Understand & rationalize requirements interdependencies across domains (software, networks, EDA, mechanical, etc.)
- Automated & guided exploration of the feasible systems design space based on the SysML model & parameters
- Automated & guided Uncertainty Quantification (UQ) for system level risk analysis
- VR/AR to collaborate & "visually experience" the system design across multi-disciplinary functional design teams



Source: Siemens Healthineers

25

Poll Question

What is the best approach to enable a MBSE digital thread/digital twin strategy?

26

Model-Based Systems Engineering

2025 Market & Industry Forum—10 April 2025

ADPAG Collaborative Research Program

CIMdata

Study Model-Based Systems Engineering (MBSE) current state and future trends


CIMdata

AEROSPACE & DEFENSE PLM ACTION GROUP

A&D PLM Action Group Survey on MBSE CIMdata All Users

1. Introduction

A&D PLM Action Group Survey on Model-based Systems Engineering

August 2024

Investment in model-based systems engineering (MBSE) initiatives is substantial, and the level of investment by industrial organizations and by solution providers is projected to rise rapidly over the next 3-5 years. To invest effectively requires insight into current state enablers and barriers, and future investment opportunities and drivers. Opportunities enabled by new technologies and advanced protocols for collaboration and interoperability. Drivers in the form of strategies and policies from government agencies, existing and emerging modeling and data interoperability standards, competitive pressures, and global dislocations. What is the true nature and value potential of these opportunities and what are the business implications of these drivers?

INCOSE defines MBSE as "the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases." Across such an expansive landscape, what can be implemented to deliver value today? In what directions and at what pace will that value footprint expand? And what are the critical prerequisites to assure success as we map out our organization's journey?

To answer these questions, CIMdata and the Aerospace & Defense PLM Action Group member companies – Airbus, Boeing, Eaton, GE Aerospace, Gulfstream, Pratt & Whitney, Rolls-Royce, Safran, and Spirit AeroSystems – are partnering with Ansys, PTC, and Siemens Digital Industries Software and The Reuse Company, all solution providers committed to addressing the MBSE challenges of industrial companies, in a major research effort. And this survey, intended to gather your perspective, is a key component of our research.

Completing the survey should take 30-40 minutes of your time. It is not necessary to complete the survey in one sitting. You may leave the survey at any point and then return later to continue with your response. Also, you need not be concerned with confidentiality. Only summary statistics and charts of your responses will be provided to our sponsors and published by the CIMdata team.

In return for your participation, you can request a summary report of research findings and request to be entered into a drawing for one of ten $100 and ten $50 Amazon gift certificates at the conclusion of the survey.

Please read and answer all the questions if you can. If you do not know the answer to a question, you can skip it and move on to the next. Also, you can exit and return later to complete the survey. If you exit before completing the survey, the system will display a unique URL. You must make a note and enter this URL when you return to access your survey instance.

Thanks in advance for your participation and let's get started!

Sponsors

ANSYS · ptc · AEROSPACE & DEFENSE PLM ACTION GROUP · THE REUSE COMPANY · SIEMENS

Objective

The A&D PLM Action Group members and the PLM solution provider sponsors share a common objective for this research –

To gain understanding of needs and opportunities within industry that will inform Digital Thread solution strategy and roadmap and implementation planning

27

Co-Directors, CIMdata's SDSD Practice

CIMdata

Don Tolle, Co-Director, Simulation-Driven Systems Development Practice

Over 40 years of experience in engineering design, simulation and test domains, including software product development, MBx implementation consulting, go to market strategy development and strategic partnering/M&A. Broad scope of senior positions with PLM/CAE/Test software & engineering services providers. 13+ years with CIMdata leading up the S&A and SDSD Consulting Practices.

Participant in industry working groups – INCOSE, NAFEMS A&D PLM Action Group

Sandeepak Natu, Co-Director, Simulation-Driven Systems Development Practice

Over 25 years of experience in engineering simulation, consulting, solution selling, and business development. Gained his initial professional experience with Fluent India as part of technical support and services teams with focus on academic support and process industry. Helped numerous multinational companies establish their initial computational modeling teams in India.

28

Questions & Answers

What's on your mind?

29

CIMdata Defining What Comes Next in Digital Transformation

Strategic management consulting for competitive advantage in global markets

Serving clients from offices in North America, Europe, and Asia-Pacific

World Headquarters
Ann Arbor, Michigan USA
Tel:+1.734.668.9922

EMEA Headquarters
Weert, NL
Tel:+31 (0) 495.533.666

Asia-Pacific Headquarters
Tokyo, Japan
Tel:+81.47.361.5850

www.CIMdata.com

30