Digitalization, Digital Thread, PLM & MBSE: Where to next?

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Our Mission...

Strategic management consulting for competitive advantage in global markets

CIMdata is the leading independent global strategic management consulting and research authority focused exclusively on the PLM market.

We are dedicated to maximizing our clients' ability to design and deliver innovative products and services through the application of PLM.

PLM – CIMdata's Definition

Digital transformation of the lifecycle—enabled by a product innovation platform

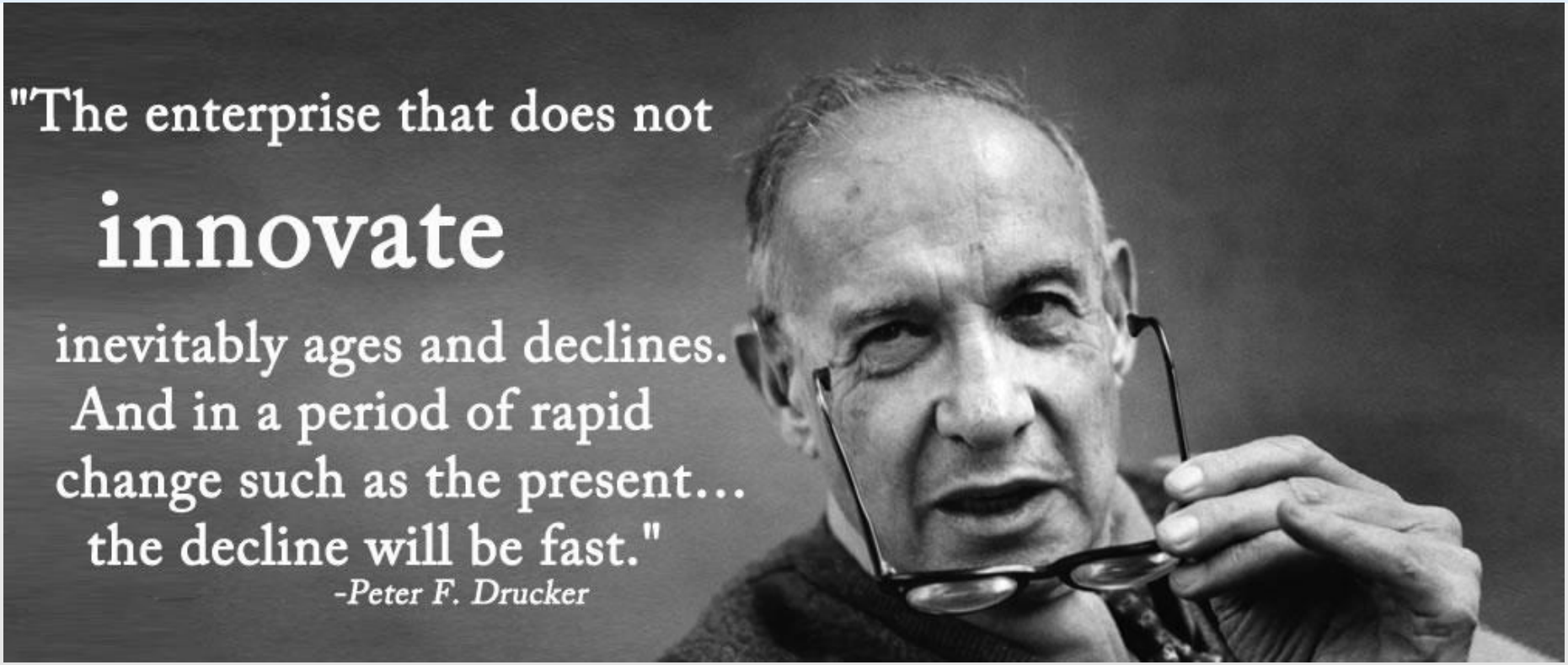
- Strategic business approach
  - *NOT* just technologies
  - Consistent set of business solutions
- Collaborative creation, use, management & dissemination of product related *intellectual assets*
  - All product/plant definition information – the virtual product
    - AEC, MCAD, EDA, ALM, SE, requirements, simulations, analytics, portfolio, formulas…
  - All product/plant process definitions – the virtual processes
    - Processes that plan, design, produce, operate, support, decommission, recycle…
- An innovation platform that supports the extended enterprise
- Spans the full lifecycle, from idea/concept through life

Digitalization: Transforming Enterprises

Digitalization requires rethinking the business, product, and data

- Radical advances in digitalization are underway all around us
- Digitalization itself as been defined in many ways, but the most succinct is the business strategy best geared to extract real-world value from digital data (e.g., Airbnb, Amazon, etc.)
- The Internet of Things (IoT) with its billions of connected devices is and will play a major role
  - A source of "big data" and enabling closed loop lifecycle management
  - Making the digital thread and digital twin more achievable

“Digitalization” accelerates change & innovation



“Digitalization is the main reason just over half of the companies in the Fortune 500 have disappeared from the list since 2000.”

Pierre Nanterme, CEO Accenture, World Economic Forum

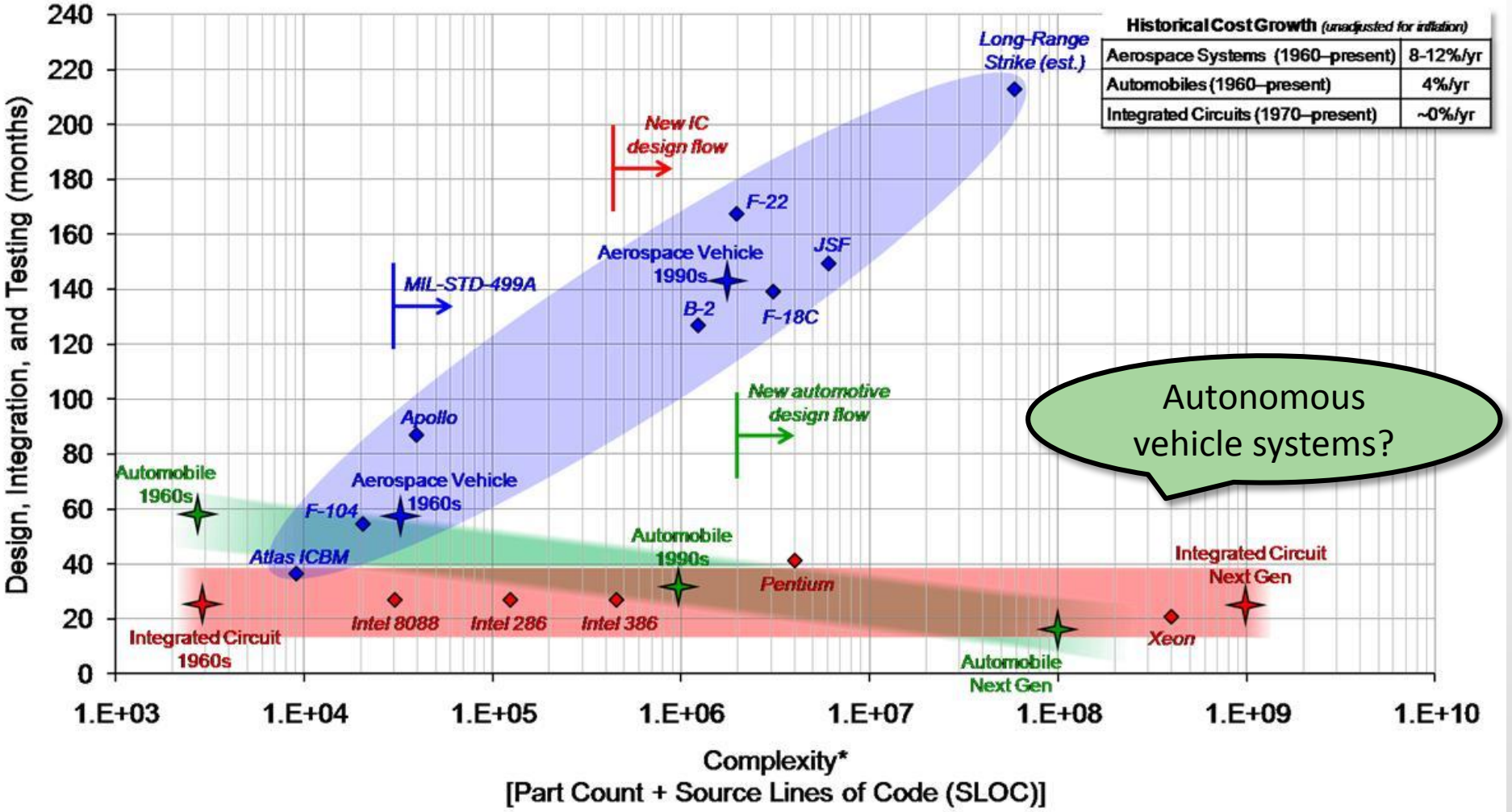
Complexity = Risk, Digitalization = Opportunity

Business Success now requires a Model-Based Systems Engineering approach

- Cyber-physical systems- Electronics & software growing
- New mfg processes & materials—lighter, stronger, green
- Increased regulatory requirements across all industries
- Consumers demand “mass customized” products… Now!
- Shorter lifecycles = continuous product innovation
- Yet extremely long systems lifecycles in select industries
- “Industrial IoT” environment = constant market feedback

Complex market requirements demand more upfront cross-domain engineering

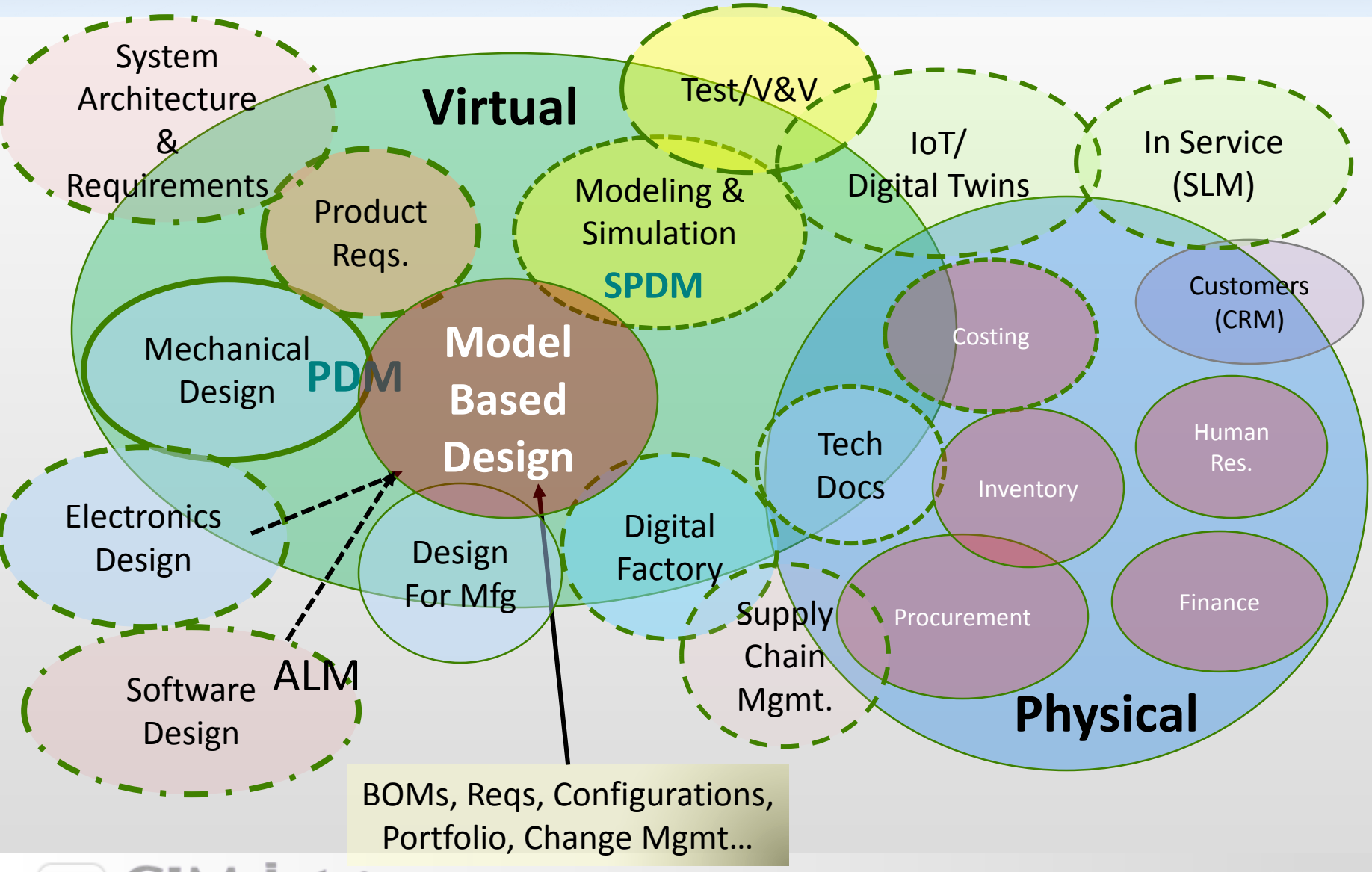
The Complexity Issue cuts across Industries



Source: DARPA AVM presentation.

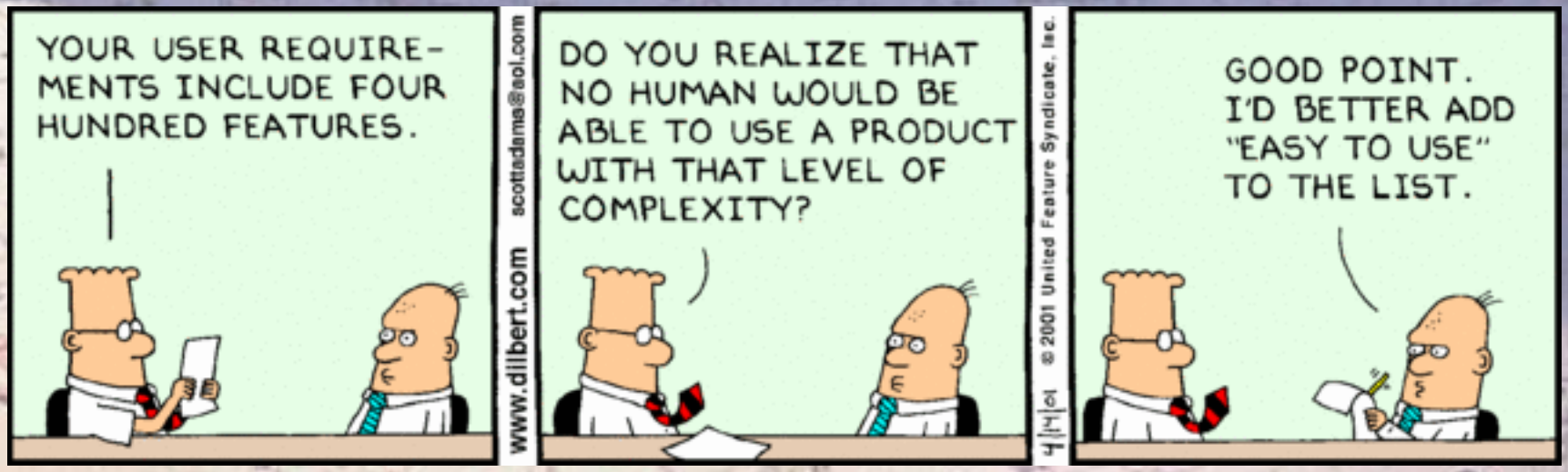
Relationship of Digital Initiatives ("As Is")

Key domains in model-based are typically managed partially or totally in silos today



Can there really be a digital master model?

Often competing requirements and digital data distributed across domains



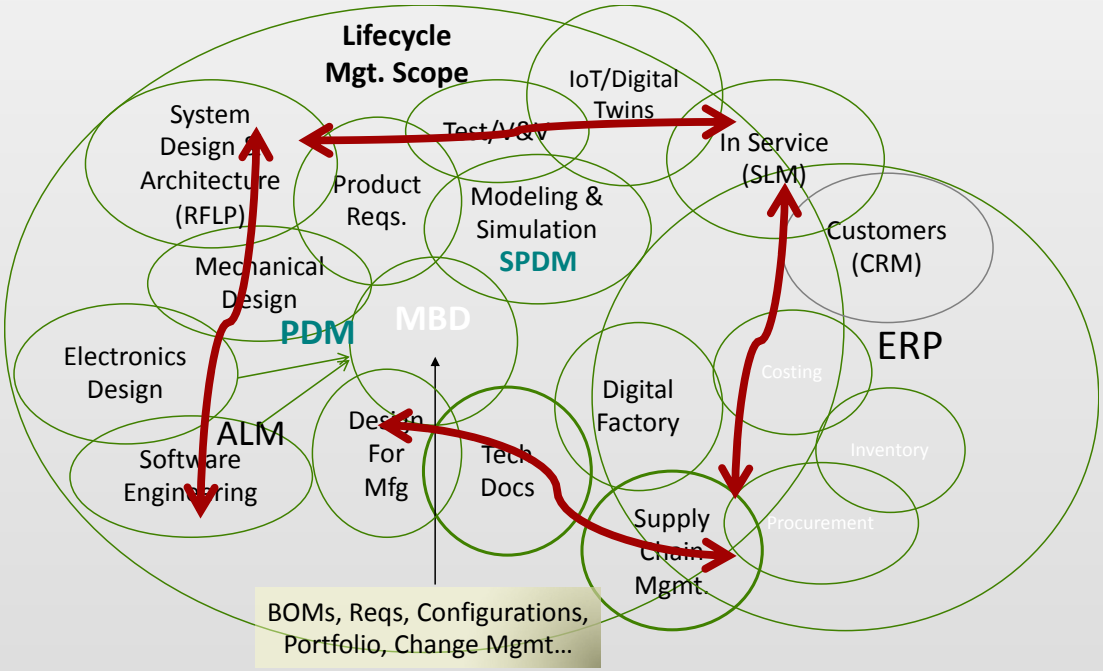
Which models are most critical to connect in meeting the overall design requirements and with lifecycle traceability? …some…all…?

Digital Thread

CIMdata's preferred definition

- ***Digital Thread*** refers to the communication framework that allows a **connected data flow and an integrated view** of a physical asset's digital data (i.e., its Digital Twin) throughout its lifecycle cutting across traditionally siloed functions

Digital thread is enabled and supported by a robust end-to-end and connected systems model and related MBx processes



Extracted from: https://www.dodmantech.com/ManTechPrograms/Files/AirForce/Cleared_DT_for_Website.pdf
Also see: http://www.manufacturing-operations-management.com/manufacturing/2016/04/what-is-the-digital-thread-and-digital-twin-definition.html

The Emergence of the Digital Platform

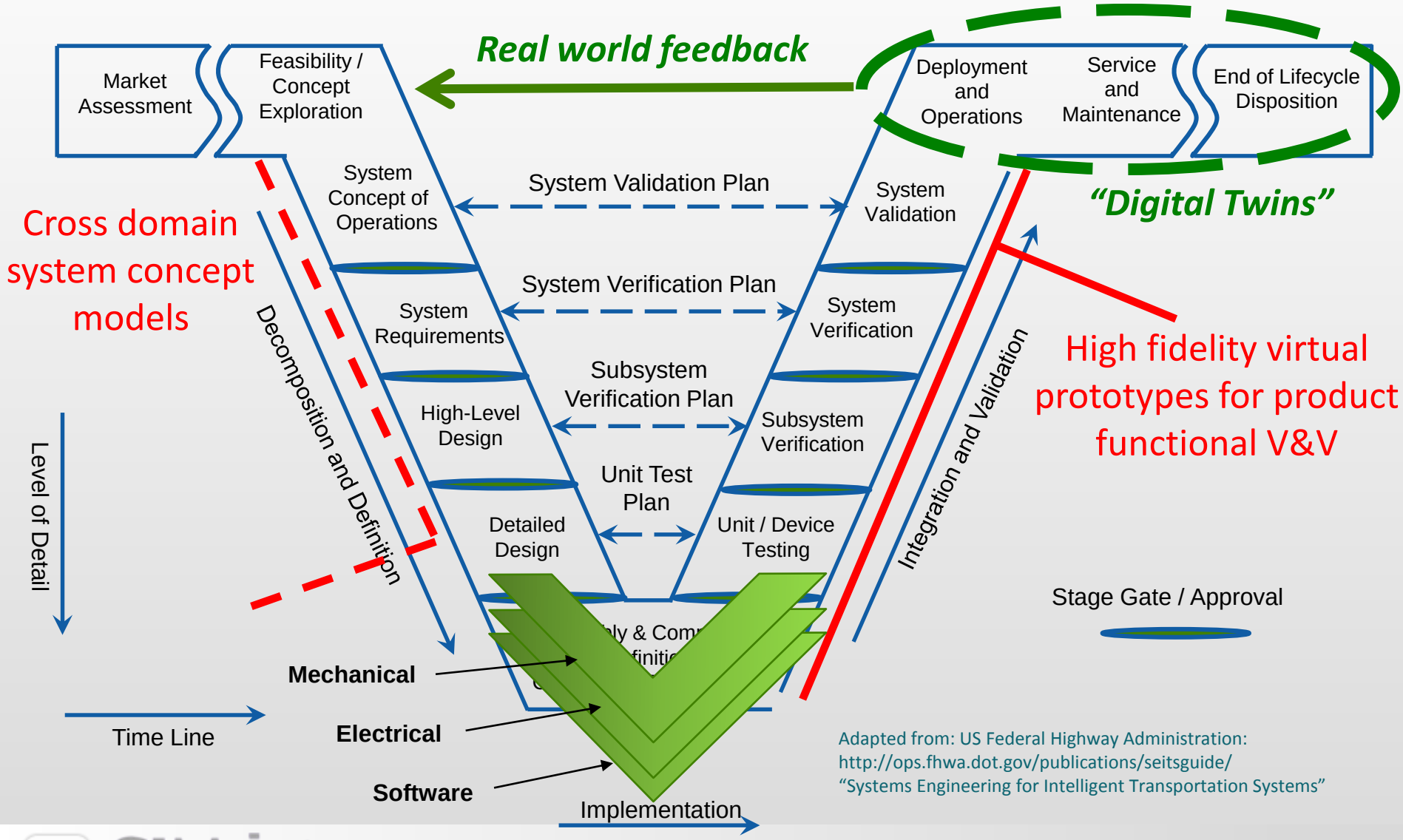
Platformization, the next evolution of PLM, required to support digitalization

Proliferating digital platforms will be at the heart of tomorrow's economy, and even government...

The Economist, January 18th, 2014

Model-Based Enables Systems Engineering

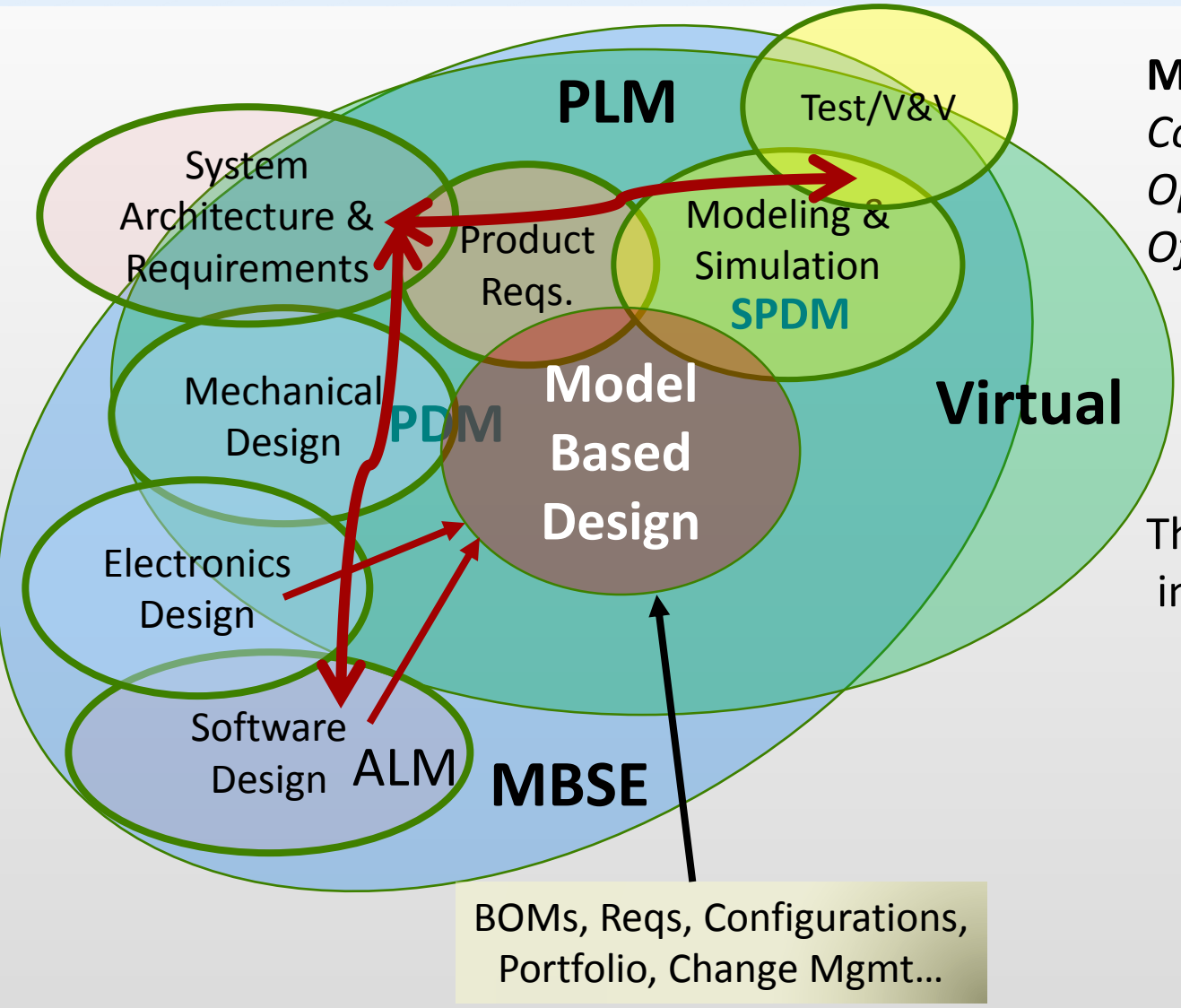
Digital collaboration enables high-value information continuity across lifecycle processes



Adapted from: US Federal Highway Administration:
http://ops.fhwa.dot.gov/publications/seitsguide/
"Systems Engineering for Intelligent Transportation Systems"

Sewing the MBSE Digital Thread ("To Be")

Conceptual Systems Engineering across domains; connections to PLM/M&S for V&V



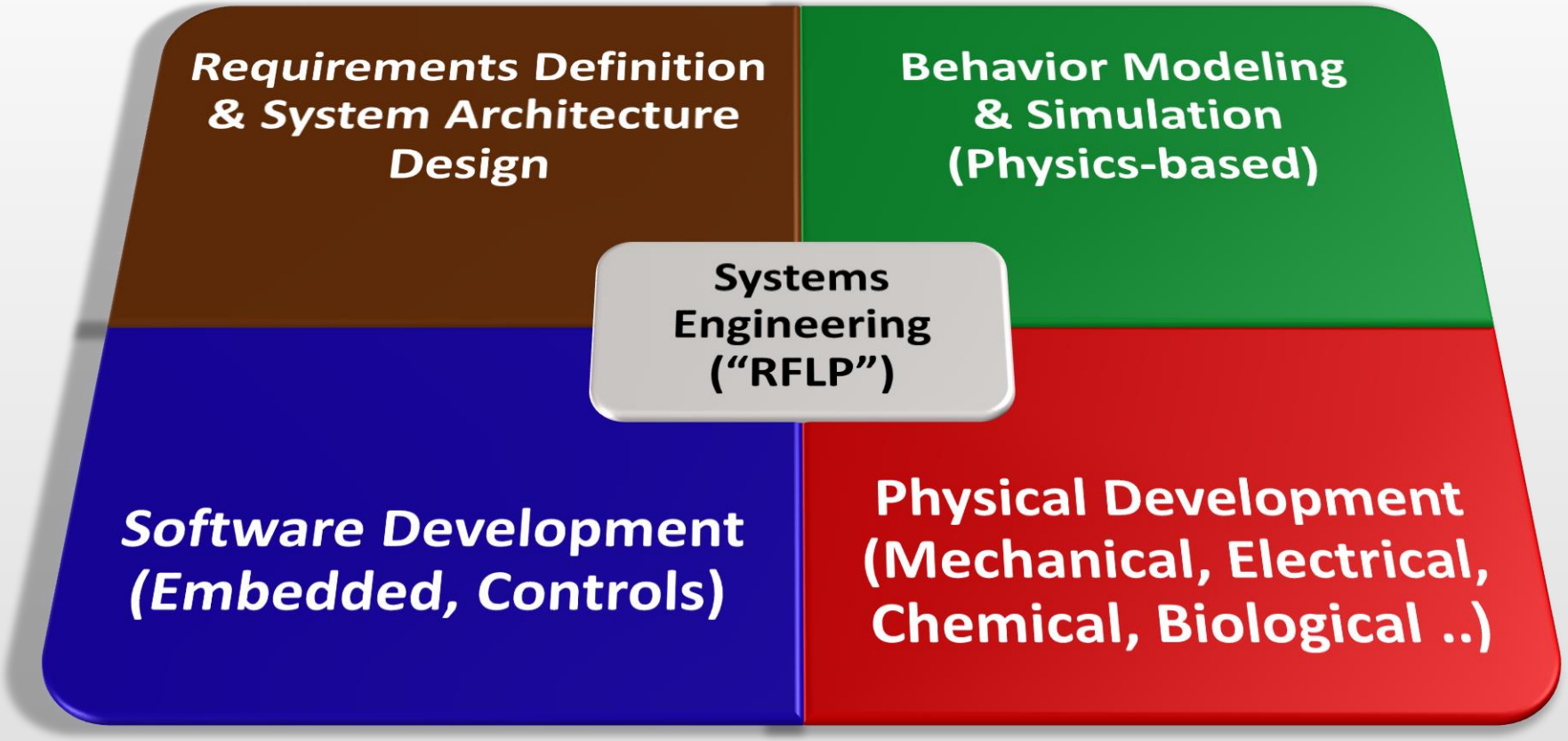
MBSE Use Case:
Conceptual Design, Optimization and Validation Of Cyber-Physical Systems

The thread needs to connect information across domains:

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

Platforms are now consolidating across domains

PLM vendors acquiring MBSE, M&S, ALM, EDA & IoT technologies



But still too way many tools in use for any single solution vendor to cover all the required disciplines

Platforms are now consolidating across domains

Leading vendors acquiring MBSE, ALM, EDA & IoT technologies

PTC acquired Atego (Now Integrity MBSE suite); Strong focus on IoT platform

Dassault Systemes acquires Dymola and recently NoMagic/MagicDraw for MBSE

Siemens PLM acquires Polarion(ALM), Mentor Graphics(EDA), Mindsphere (IIOT)
- MBSE Partnership recently announced with OBEO(Capella)

Aras introducing new capabilities for System Architecture and Requirements

IBM Rational Suite formed from Telelogic acquisition (DOORS) and Rhapsody
- Products outsourced to third parties; Focus now on IoT/Watson

ANSYS acquires SCADE, Apache Design (EDA) and Esterel & KPIT (software)
- Partnering with PTC and SAP to provide physics-based Digital Twin solutions

Notable event- Jama Software receives $2000M in private equity investment

2017 Market Results

Results by segment (US$ Millions) mostly positive

Segment	2017 Revenues	YoY Growth
cPDm Comprehensive Technology Providers	$5,795.7	2.9%
cPDm-Focused Applications	$2,227.1	6.5%
Digital Manufacturing	$761.8	6.2%
SI/Reseller/VAR	$7,013.6	10.1%
Tools		
MCAD-Multi Discipline	$3,786.6	5.6%
MCAD-Design Focused	$2,848.2	7.2%
Non-Bundled CAM	$1,367.7	7.7%
Simulation & Analysis	$5,710.5	8.2%
Other Tools (e.g., SE, ALM)	$1,389.3	8.2%
EDA	$9,117.2	8.9%
AEC	$3,584.7	6.6%
Total	$43,602.3	7.3%

Estimates are US$ (Millions)

Market Forecasts

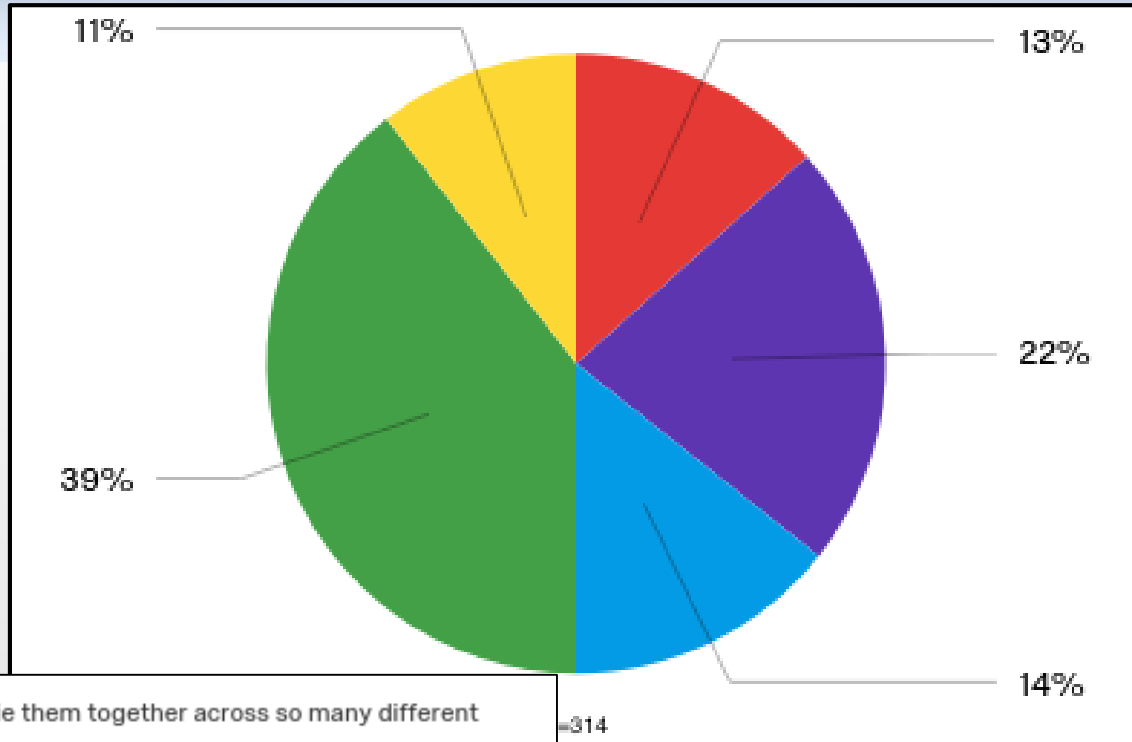
For 2018 (US$ Millions) and 5-year compound annual growth rate (CAGR)

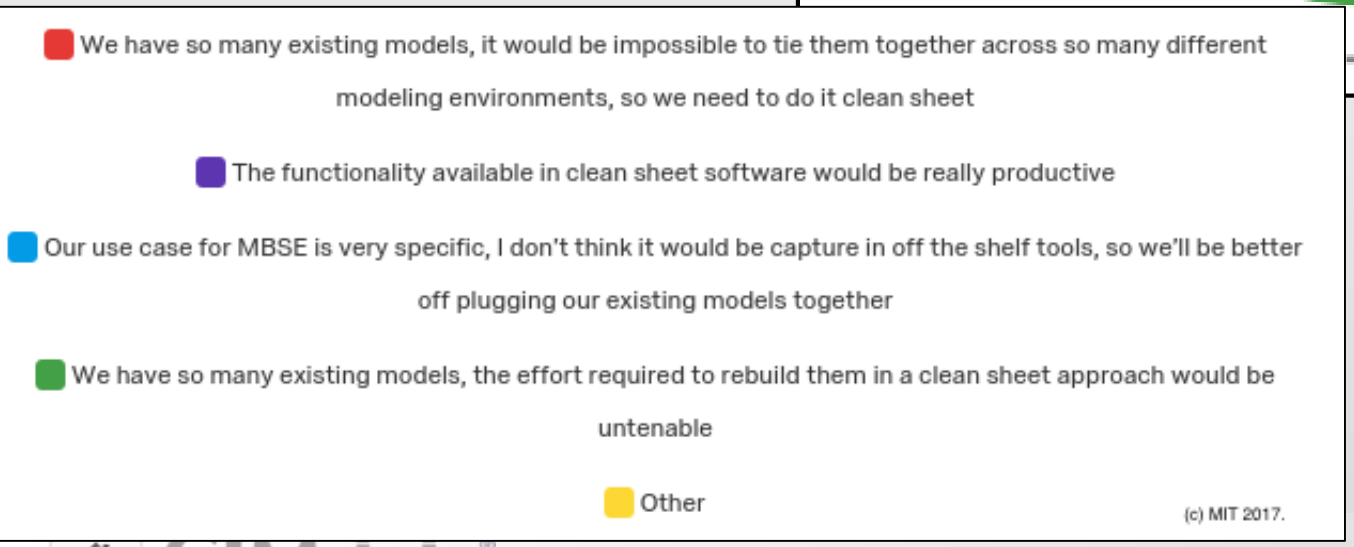
Segment	2018 Estimate	YoY Growth	5 Year CAGR
cPDm Comprehensive Technology Providers	$6,164.07	6.4%	6.6%
cPDm-Focused Applications	$2,387.49	7.2%	7.4%
Digital Manufacturing	$828.40	8.7%	9.0%
SI/Reseller/VAR	$7,478.24	6.6%	6.7%
Tools			
MCAD-Multi Discipline	$3,985.35	5.2%	5.5%
MCAD-Design Focused	$2,993.44	5.1%	5.2%
Non-Bundled CAM	$1,452.49	6.2%	6.1%
Simulation & Analysis	$6,173.07	8.1%	8.3%
Other Tools (e.g., SE, ALM)	$1,494.86	7.6%	7.7%
EDA	$9,764.57	7.1%	7.1%
AEC	$3,925.25	9.5%	7.0%
Total	$46,647.23	7%	6.9%

Estimates are US$ (Millions)

Challenge: Tool Integration, Data Interoperability

- If you pursued MBSE, would you start with a clean sheet in specific MBSE software, or would you write custom software to tie your existing models together? Why?
- *Majority indicated need to tie together existing models in some manner*



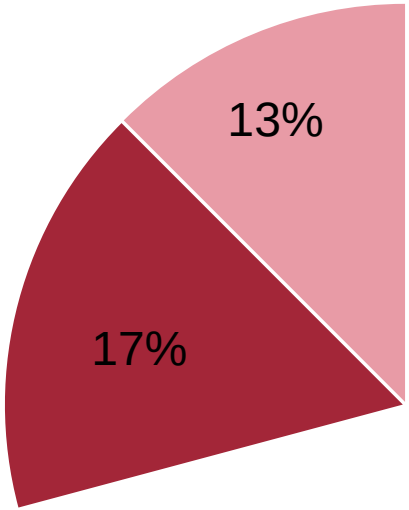


MIT MBSE On-line Course Survey of 300+ Engineers

Bruce Cameron, TSP MBSE LinkedIn blog post May 17, 2017

MBSE Users: Standards Identified as Major Gap

The MBSE GAPS



13%

30%
Standards

- Define/Justify MBSE
- Training-Implementation
- Integrate with PLM
- Standards - Interoperability
- Vocabulary
- Tool Integration (Vendors)
- Roadmap
- Modeling

"…just because you have a model doesn't mean you are model based…"

98 participants, 12 teams, 33 written submissions and 104 comments

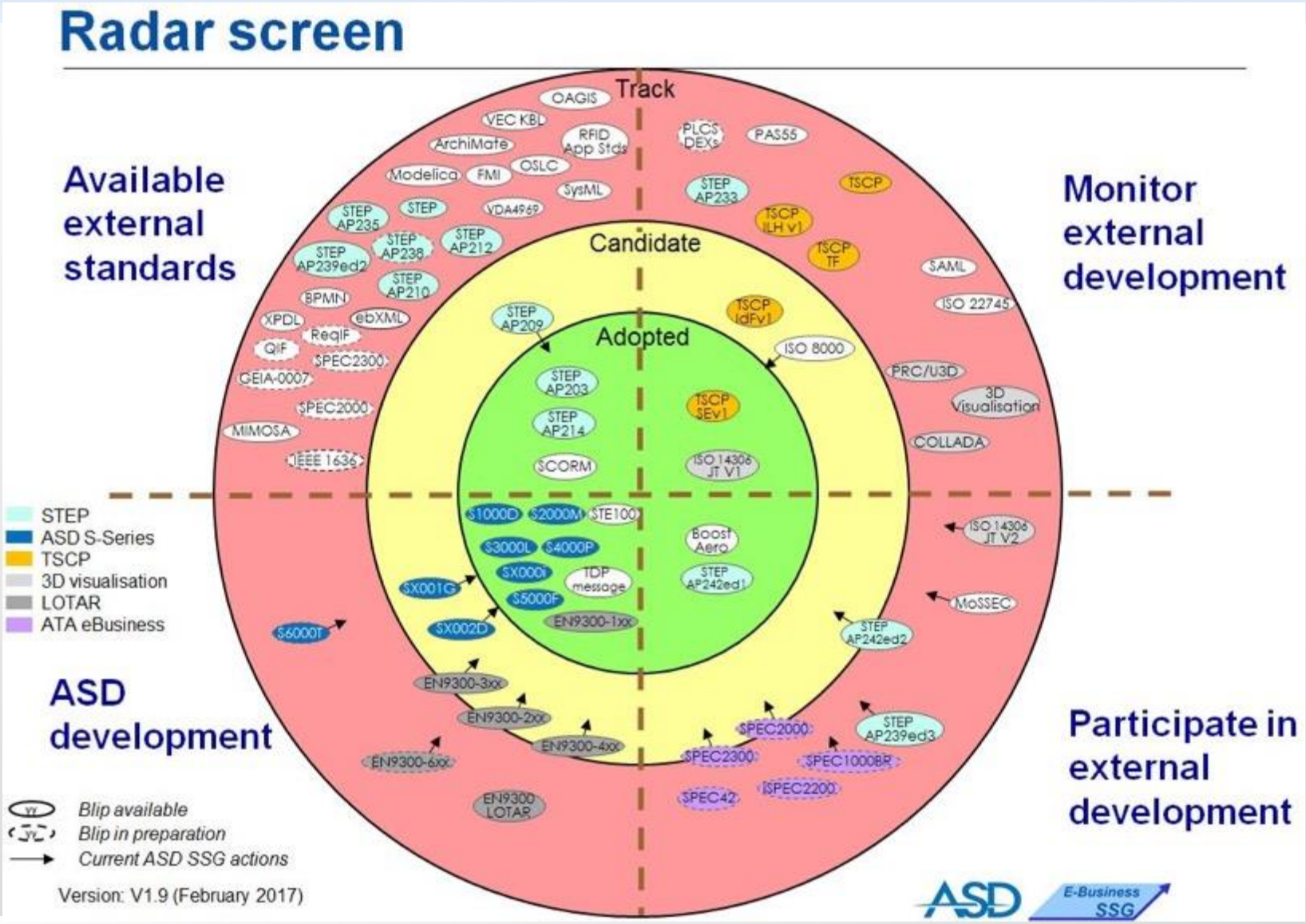
Why we need MBx Interoperability Standards

- Deal with Complexity of Digital Information
- Reduce Product Lifecycle Costs $$
- Control/Improve Product and Process Quality
- Support Design Reuse of Data and Models Across Engineering Domains & Enterprise
  - Long Term Archiving & Retrieval (LOTAR)
- An Avenue for Data Exchange & Collaboration
  - Across the entire product lifecycle
  - Across the extended virtual enterprise including suppliers

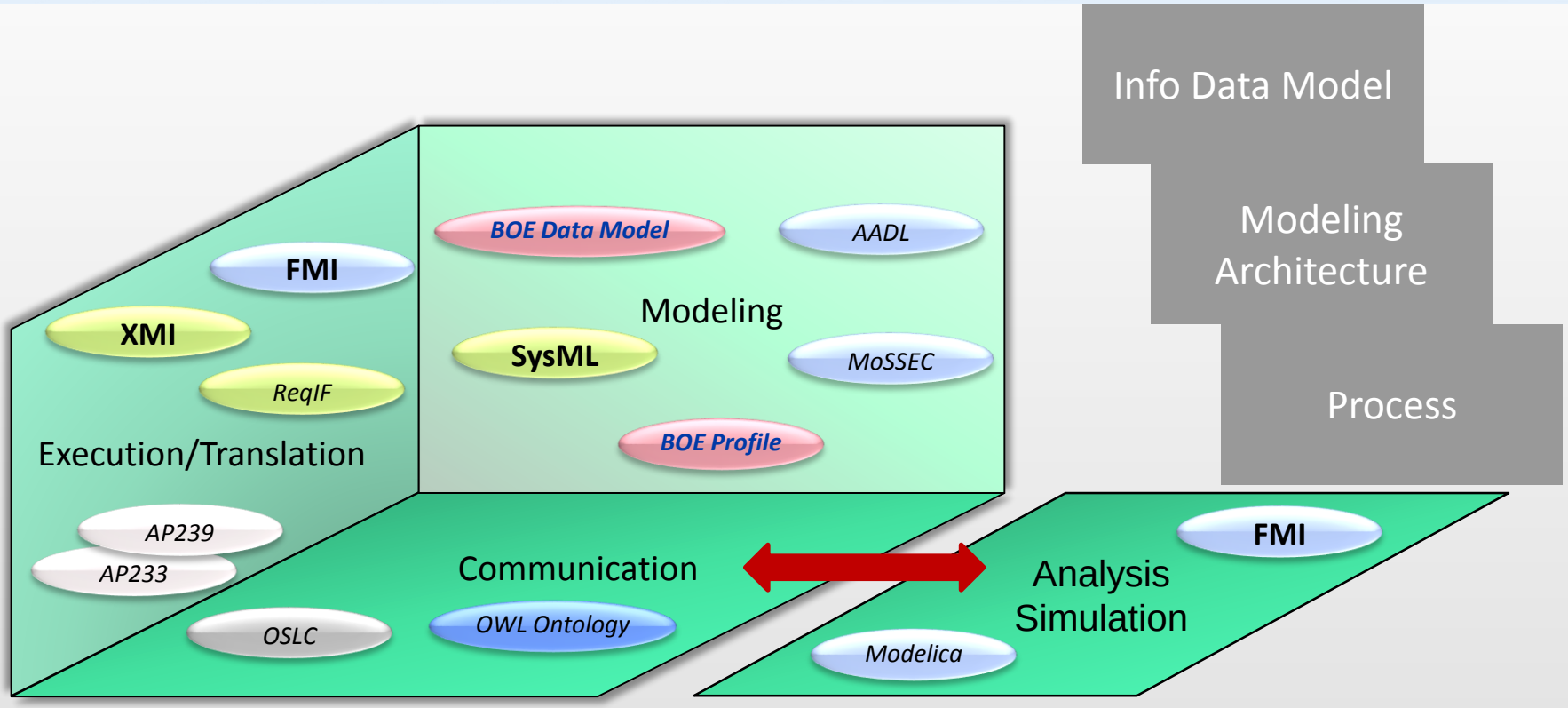
Remember early cell phone “standard” connectors?

- Lack of standards is bad but..
- Too many “standards” are equally a problem for practical implementation and widespread adoption by industry & solution providers

A&D Industry View of PLM Standards Universe



High Impact Standards- Critical MBSE Enablers



CREDIT: Bill Chown, Mentor Graphics; MBSE Roundtable, 2015 GPDIS

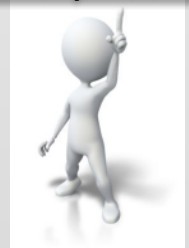
MoSSEC: Emerging Standard to Enable MBSE

Combining Modelling and Simulation Data with Collaboration Data:

Who, What, Where, When, How & Why

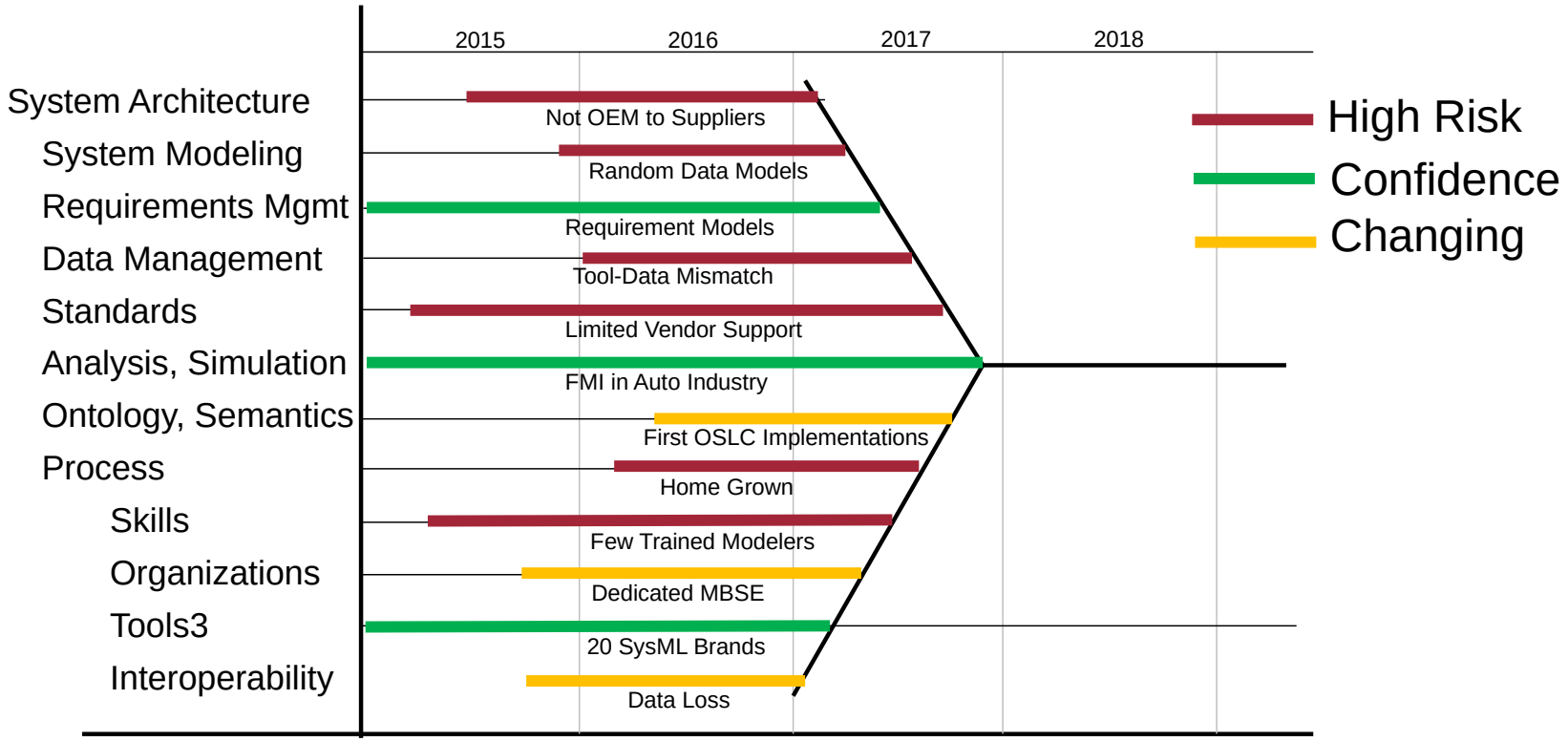
Modelling and Simulation data
- Managed by PLM/SPDM tools
- Exchanged with technical standards

Together this supports a lifecycle model-based enterprise



PDT Europe
October, 2017

Progress Being Made in Certain Areas



Sewing the MBSE Digital Thread ("As Is")

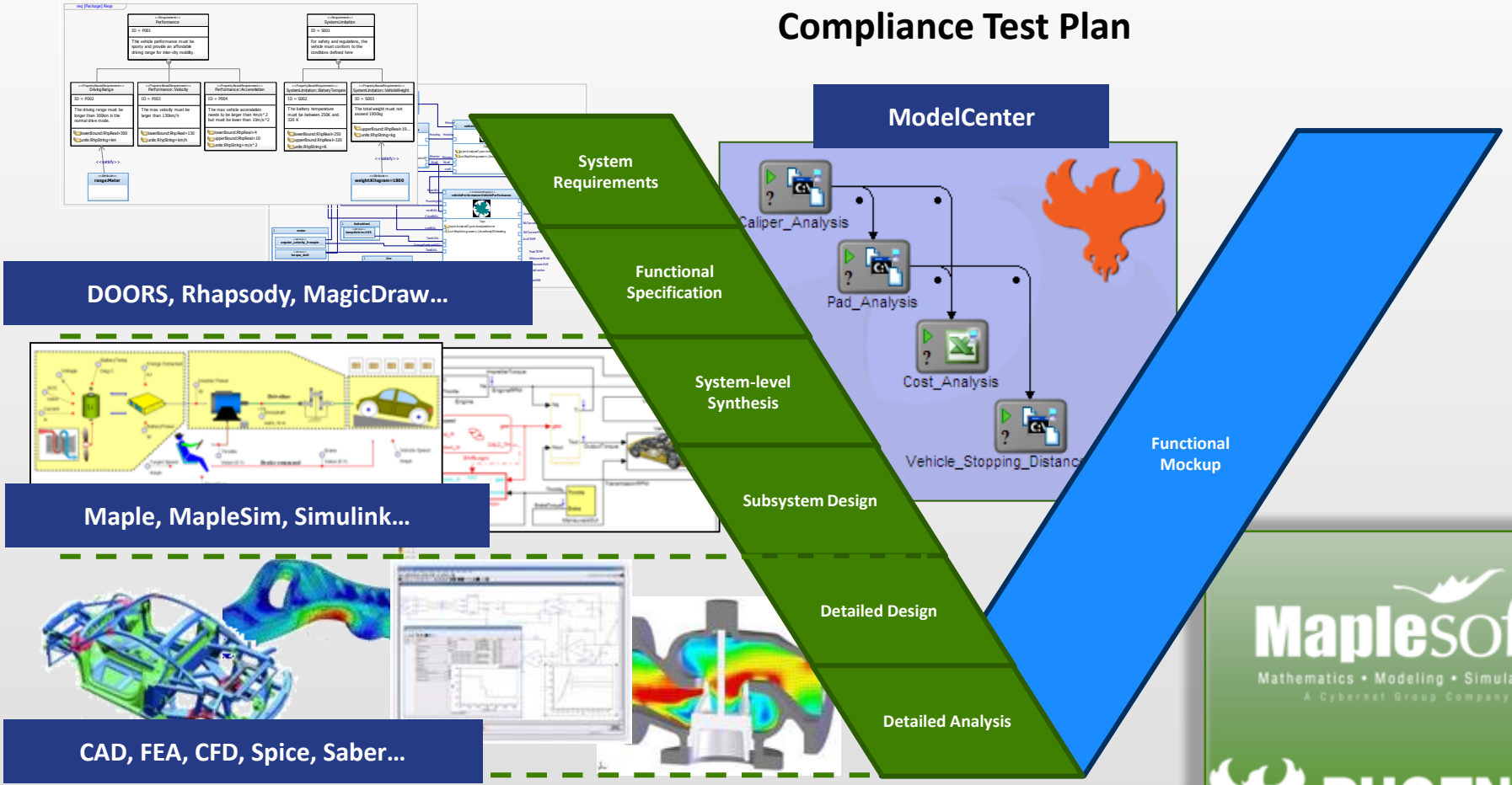
Significant collaboration efforts underway to integrate data and processes

OEM/Supplier Model Collaboration Process for MBSE

- Maturity of the SysML authoring tools and the standards for data/model exchange are at a level similar to the 3D MCAD tools in the early/mid-1990s
  - While CAD data interoperability tools are much more robust/mature today, challenges remain in working with large amounts of 3D data in heterogeneous environments
- 3-D MCAD interoperability was addressed primarily by smaller, more innovative and "authoring tool neutral" organizations that developed technology ultimately used with or even embedded within the integrated design suites of the larger MCAD software vendors (i.e., Siemens, Autodesk, DS and PTC)
  - Elysium, ITI, Spatial, ProSTEP, Anark, ProtoTech, etc.
- A similar situation appears to be evolving in the MBSE space with several smaller, vendor-neutral organizations at the forefront of working to provide data & model interoperability solutions for cross domain, multi-discipline MBSE
  - SODIUS, Ingrano/ModelBus, InterCAX, MapleSoft, Phoenix Integration

Sewing the MBSE Digital Thread ("As Is")

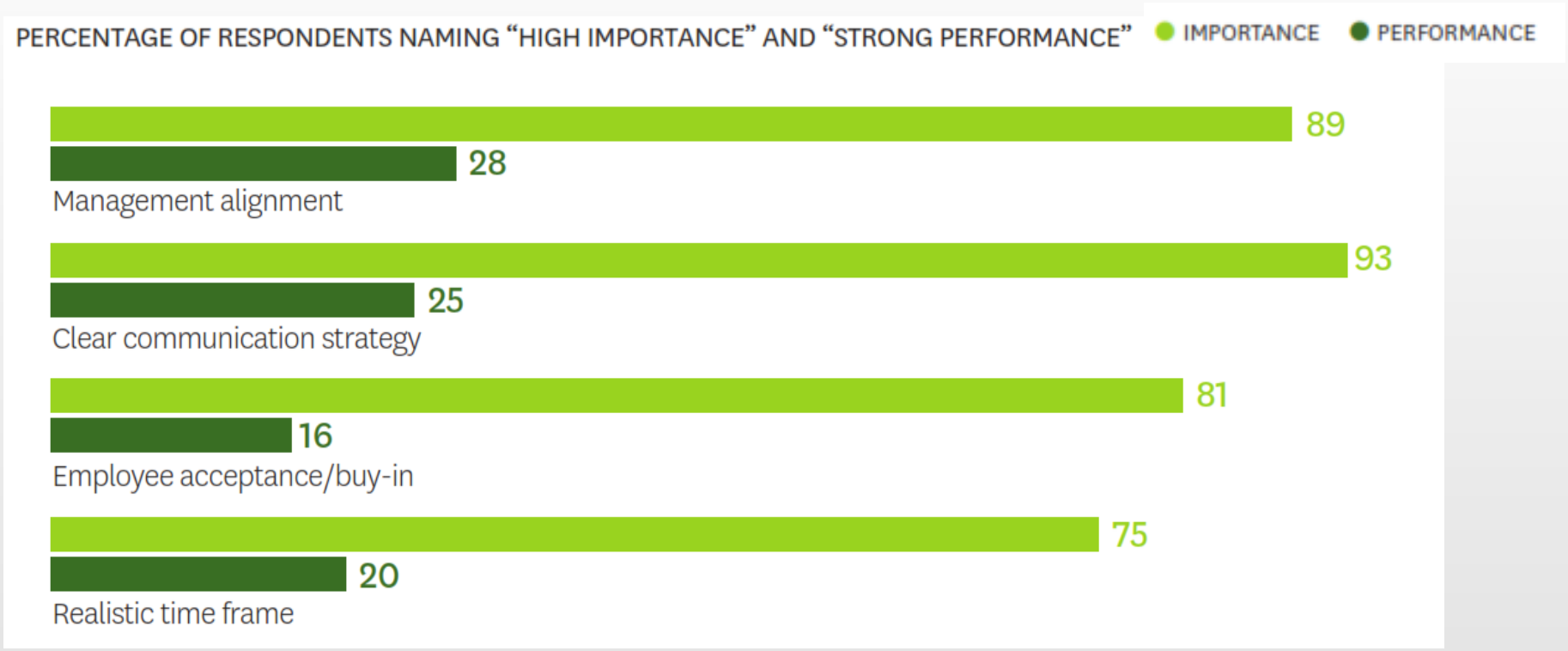
Significant collaboration efforts underway to integrate data and processes



Implementation
Software/Hardware/Procurement

Moving towards Change Success

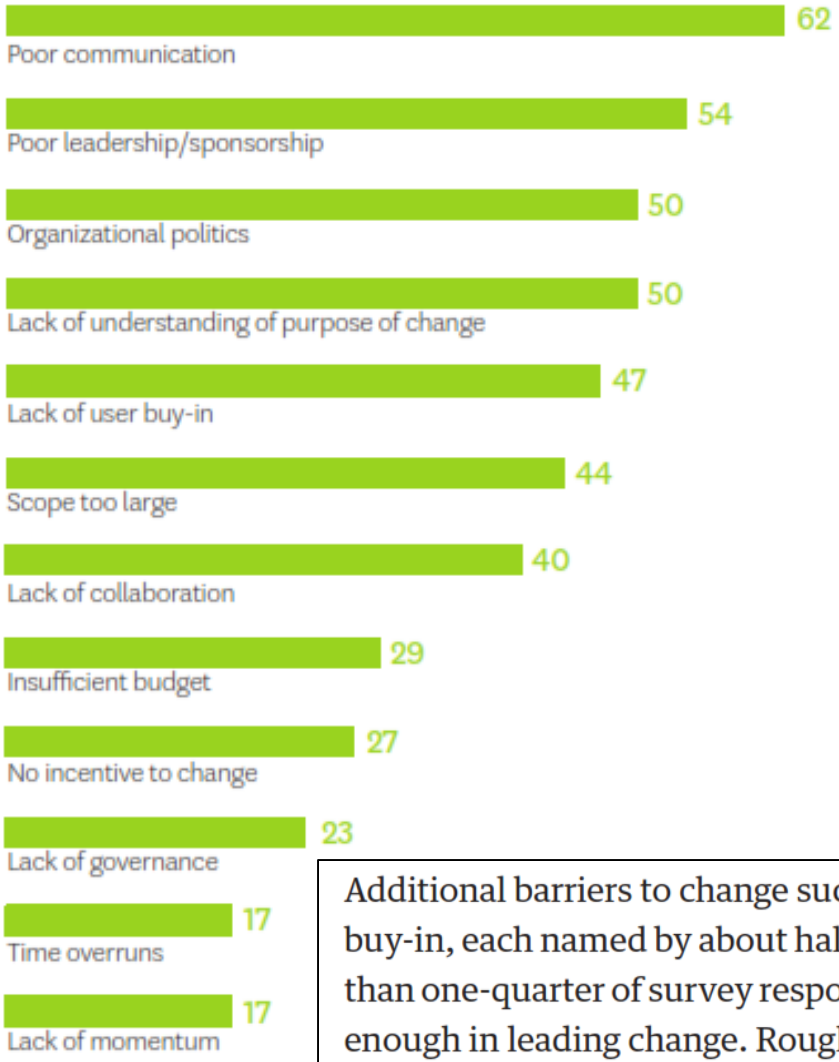
The Change Performance Gap



How important is each of the following to the success of a change initiative, and how well does the organization perform on each of these same factors when implementing the change initiative

Source: Harvard Business Review Analytic Services Survey, May 2016

Cultural Change: Critical Points of Failure



Based on a Harvard survey:

Percentage indicating which of the following are the biggest barriers to successful change

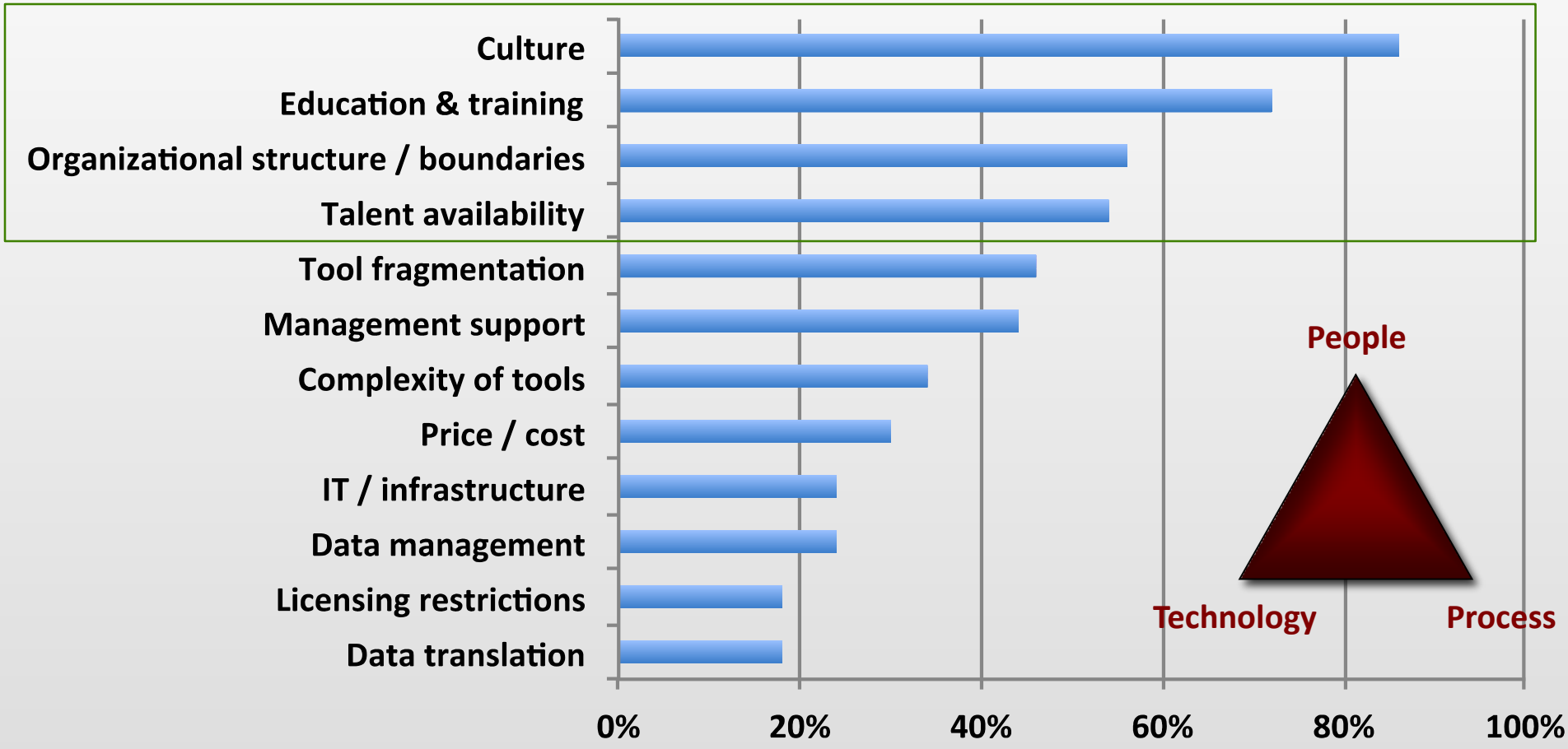
Additional barriers to change success are related to poor leadership and difficulty obtaining user buy-in, each named by about half of respondents (54 percent and 47 percent, respectively). More than one-quarter of survey respondents—26 percent—said senior leadership is often not engaged enough in leading change. Roughly the same proportion said employees are resistant to change.

Source: Harvard Business Review Analytic Services Survey, May 2016

Barriers to Industry Implementation

What users cited as problems to overcome in adopting & using MBE/MBSE

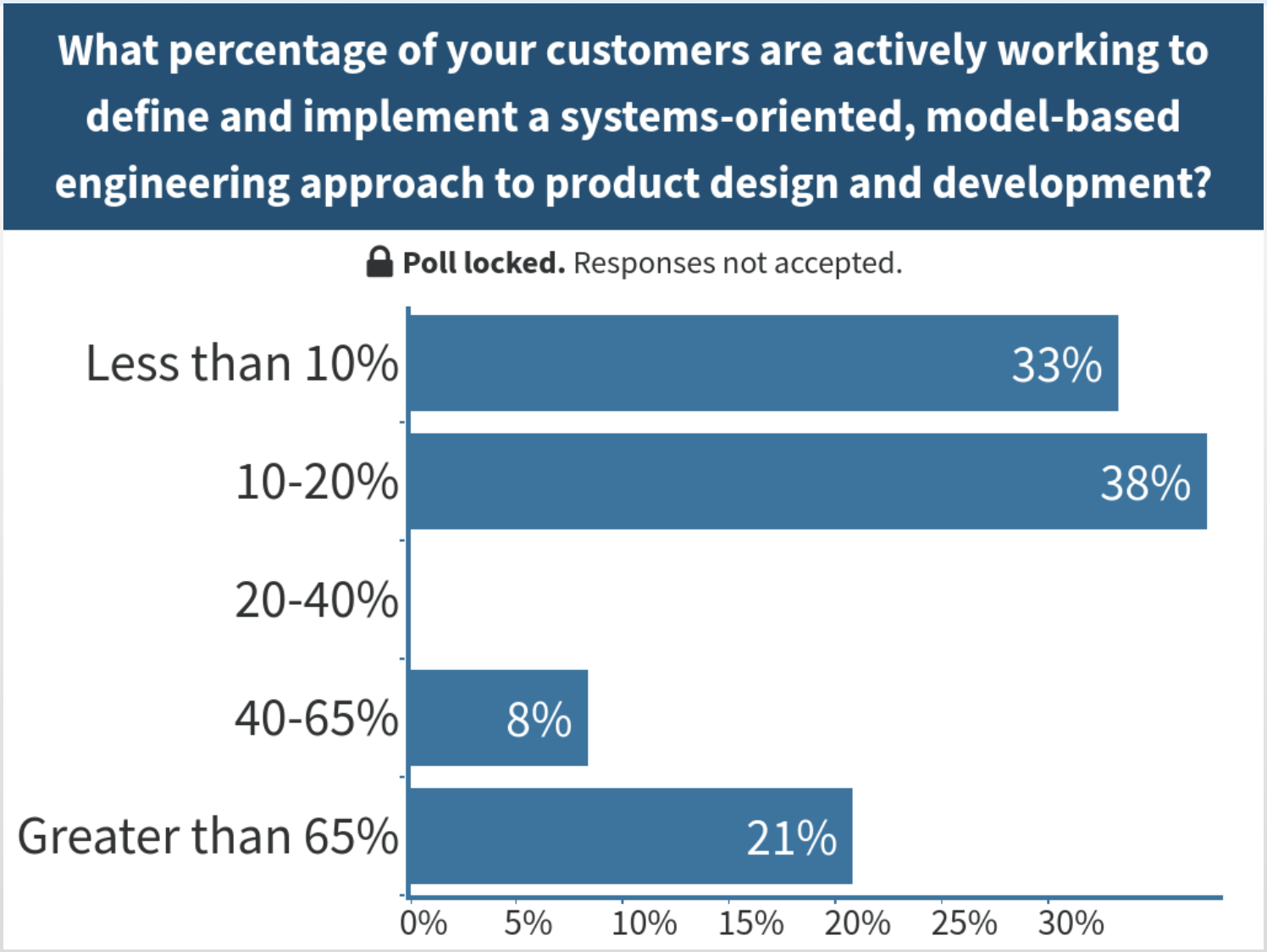
- It is about people & process as well—not just technology



Source: CIMdata MBSE web survey conducted with ANSYS & INCOSE (2015)

PLM Foresight Poll

What percentage of your customers are actively working to define and implement…



Enabling the Digital Thread Vision for MBSE

What is needed to address the industry's business needs?

MBSE solutions will ultimately require a blend of:

1) ***Process change*** leveraging MBSE best practices across industry leaders
   - This element of success is vastly underrated and may be more important as any below

2) ***Common ontology, semantics & languages*** for systems architecture design
   - *AP 2xx Unified Architecture, UML/SysML, UPDM/UAF, AADL, Capella, OWL, ST4SE?*

3) ***Innovation platforms & software tools*** for PLM/MBSE integration
   - Across engineering domains- mechanical, electrical, electronics, software, networks.
   - Across the product lifecycle- Requirements, System Architecture Design, Detailed 3D Design and Validation, Manufacturing, IoT/In-Service Operations
   - Across the global enterprise including OEM/Design Chain collaboration

4) ***Model management*** across the engineering domain data silos
   - Key business metrics- Requirements Traceability, Change Management, Configuration Management, Long-term Archiving and Retrieval (LOTAR)

5) ***Robust standards*** for PLM/MBSE data interoperability
   - XML/XMI, OSLC/RDF, ReqIF, FMI/FMU, FMI/SSP, MoSSEC (AP 234), etc.

Aerospace & Defense PLM Action Group

Project Team: MBSE Data Interoperability for OEM/Supply Chain Collaboration

AIRBUS

BOEING

BOMBARDIER

EMBRAER

GE Aviation

Rolls-Royce

Gulfstream
A GENERAL DYNAMICS COMPANY

AD PAG will be issuing a position paper by October 1, 2018

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Final Thoughts

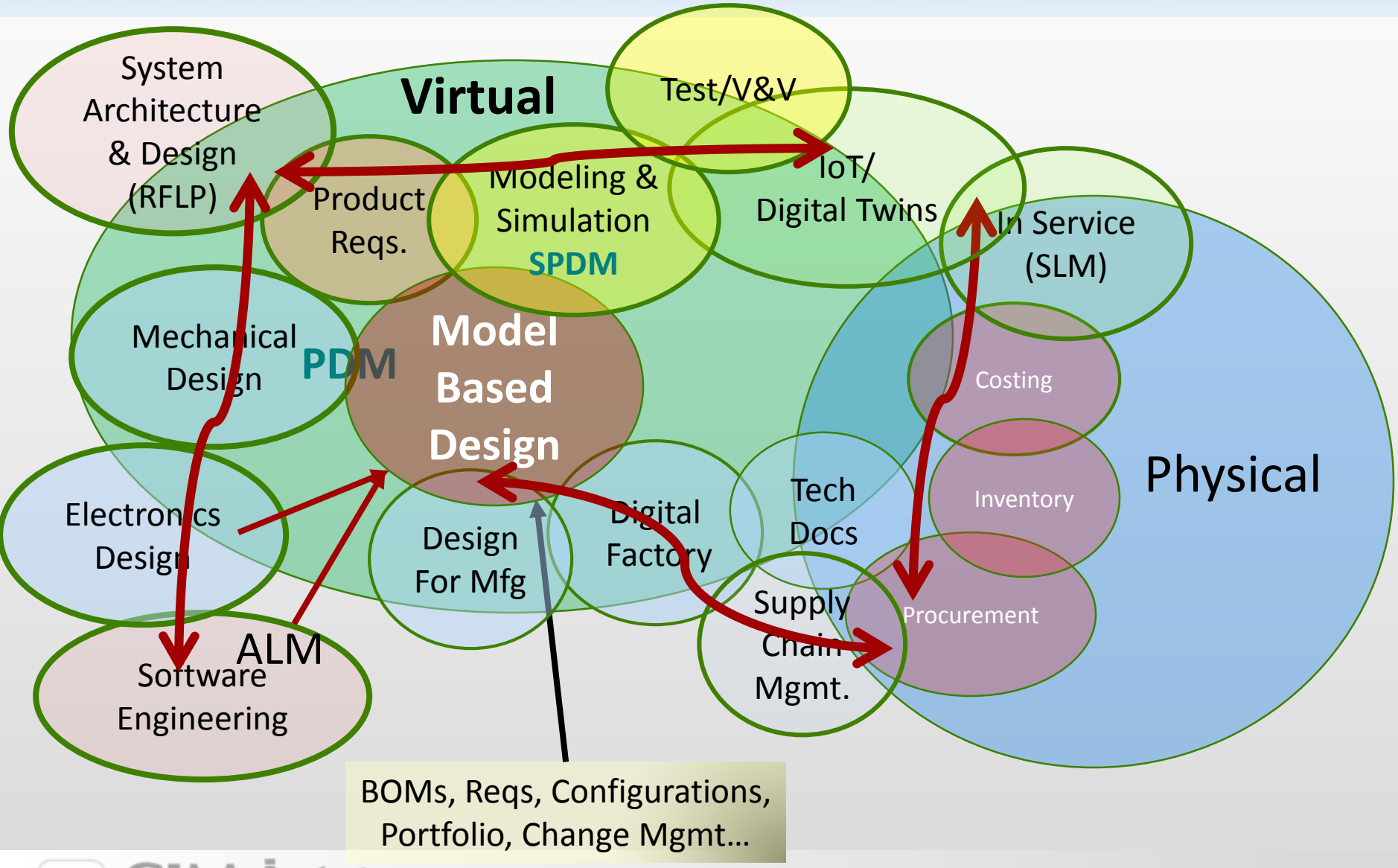
Digitalization, Digital Thread, PLM and MBSE, PLM: Where to next?

It's not about what we call it; It's about delivering value to customers and all other stakeholders of the enterprise

- MBSE needs to be defined and implemented based on specific application use cases and quantifiable ROI metrics
  - *Must account for cultural change, training & MBSE maturity growth over time*
- OEMs need to understand that they are asking suppliers to make a paradigm shift; Issues and benefits of using MBSE?
  - *Industry & DoD need to support new contractual concepts AND accept electronic project deliverables/TDPs/signoffs vs paper/documents*
- Open standards will be critical to achieving Digital Thread(s)
  - *Industry specific solutions will be based on a "platform of platforms" approach*

Connecting the Lifecycle Digital Thread

Building out all of these threads will enable the desired closed loop lifecycle process



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