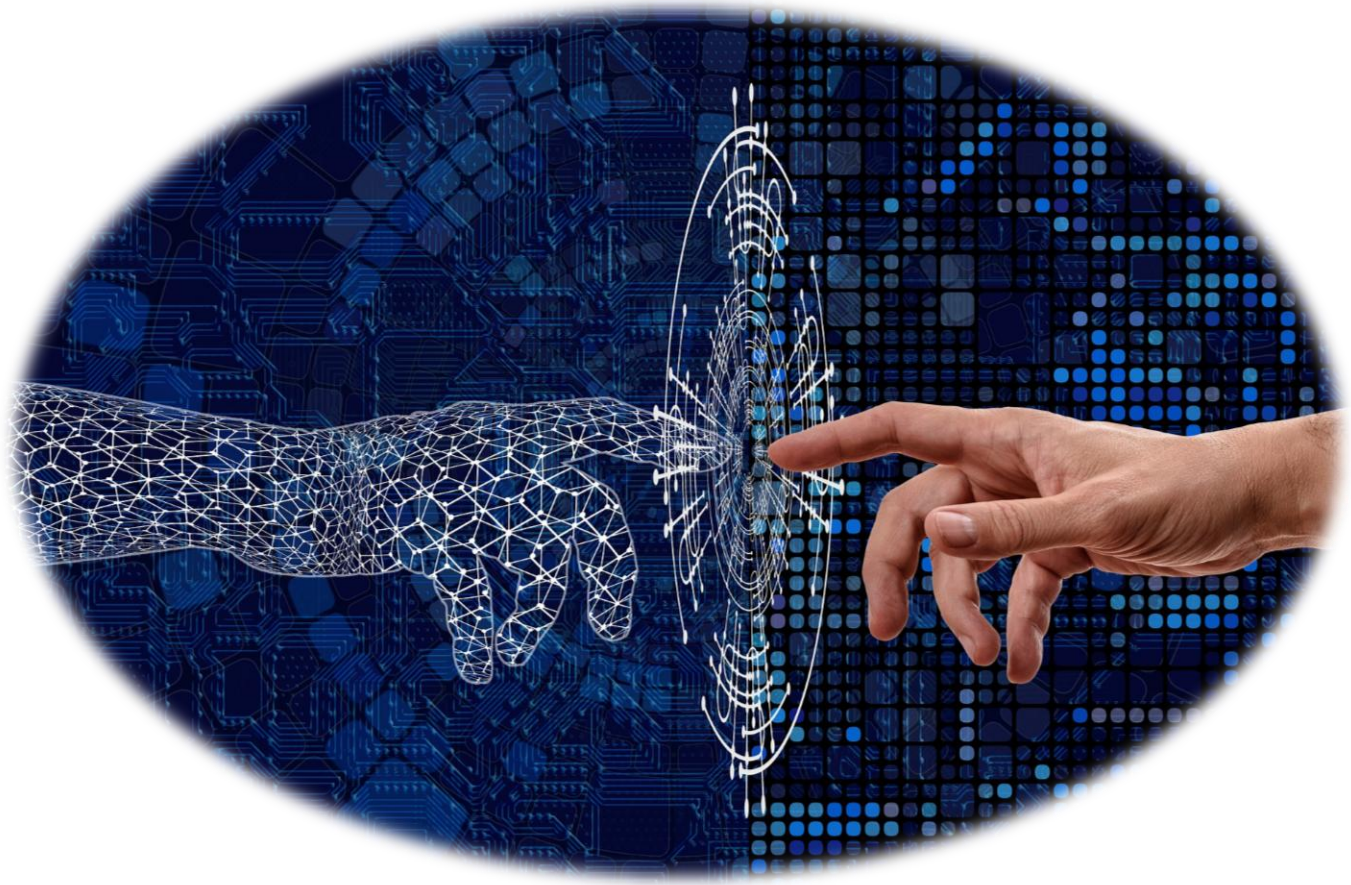
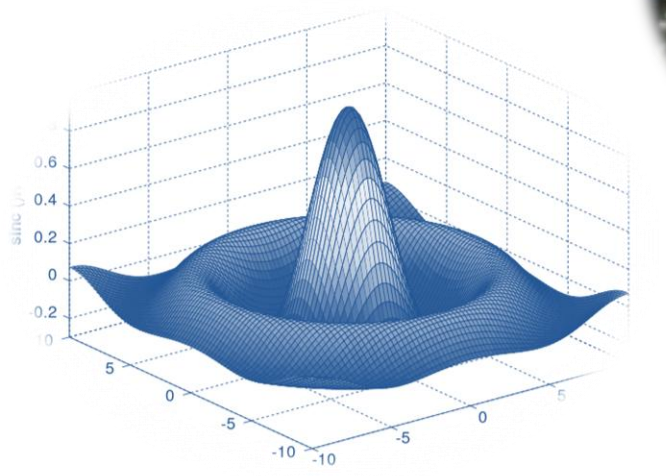
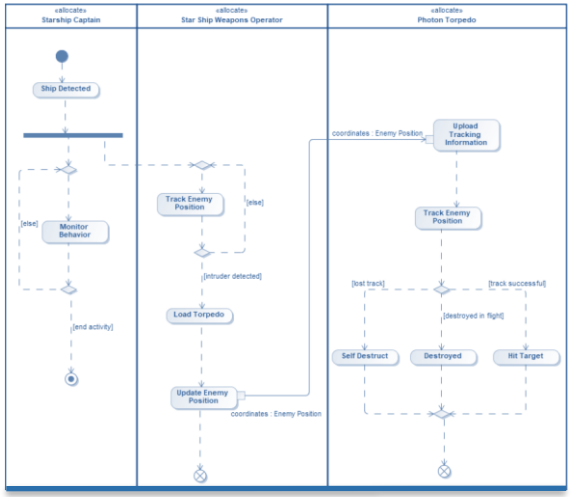


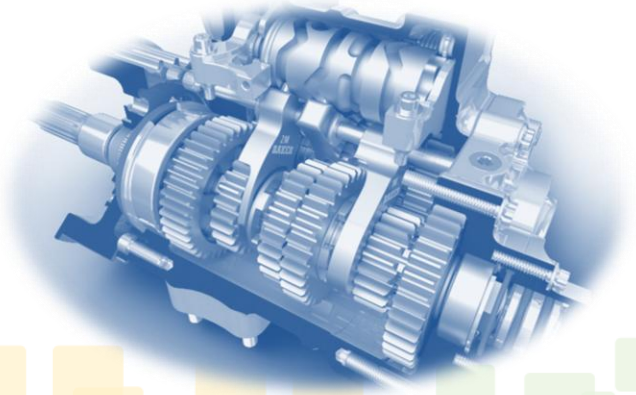
Into the Great Digital Unknown

Model-Based Systems Engineering and Digital Engineering

What Do You Envision?

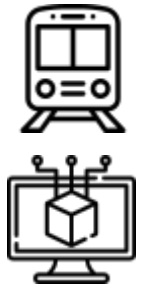






Appreciating a Changing Context

From Static Products to Intelligent Systems of Systems

Product	Smart Product	Smart, Connected Product	Product System	Systems of Systems
				

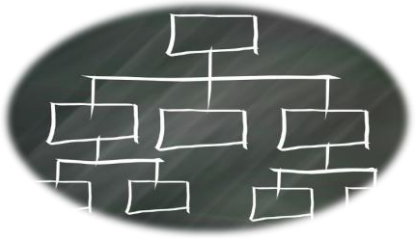
Electro-mechanical

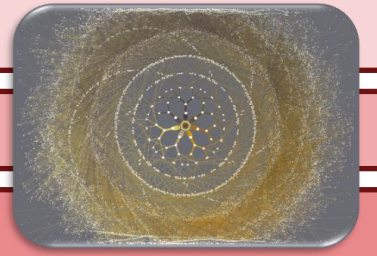
Cyber

Connected

Coordinated

Collaborating





Icons made by Freepik from www.flaticon.com

Adapted from Claas, November 2019

Exceeding the Capabilities of Traditional Engineering

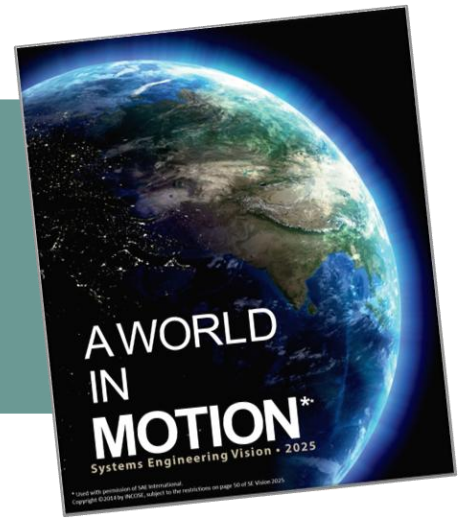
Systems Challenges in Today's World

1. **Mission complexity is growing faster than our ability to manage it . . . increasing mission risk from inadequate specifications and incomplete verification.**

2. **System design emerges from pieces, rather than from architecture . . . resulting in systems that are brittle, difficult to test, and complex and expensive to operate.**

3. **Knowledge and investment are lost at project life cycle phase boundaries . . . increasing development cost and risk of late discovery of design problems**

4. **Knowledge and investment are lost between projects . . . increasing cost and risk: dampening the potential for true product lines.**



An Explosion in Complexities and Expectations

- System scale
  - Mission complexity
    - Technology complexity
      - Project team complexity
        - Dynamic complexity
          - Build to order
            - Cycle time

It is not necessary to change.
Survival is not mandatory.

Responding to a Changing World

Leveraging today's capabilities to engineer tomorrow's solutions

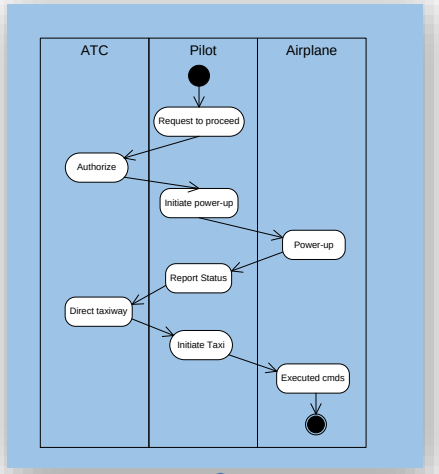
Towards Model-Based Systems Engineering

A Practice in Transition

Traditional

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

Future



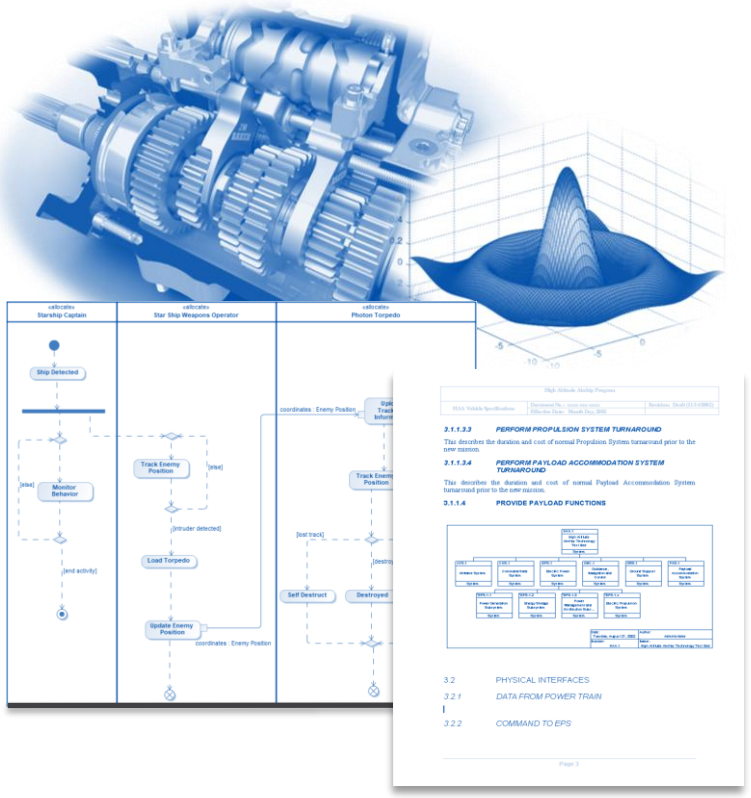
Moving from document-centric to model-centric

Reprinted from INCOSE Model-Based Systems Engineering Workshop, February 2010

“Defining” Models and MBSE

A graphical, mathematical (symbolic), physical, or verbal representation or simplified version of a concept, phenomenon, relationship, structure, system, or an aspect of the real world

www.businessdictionary.com



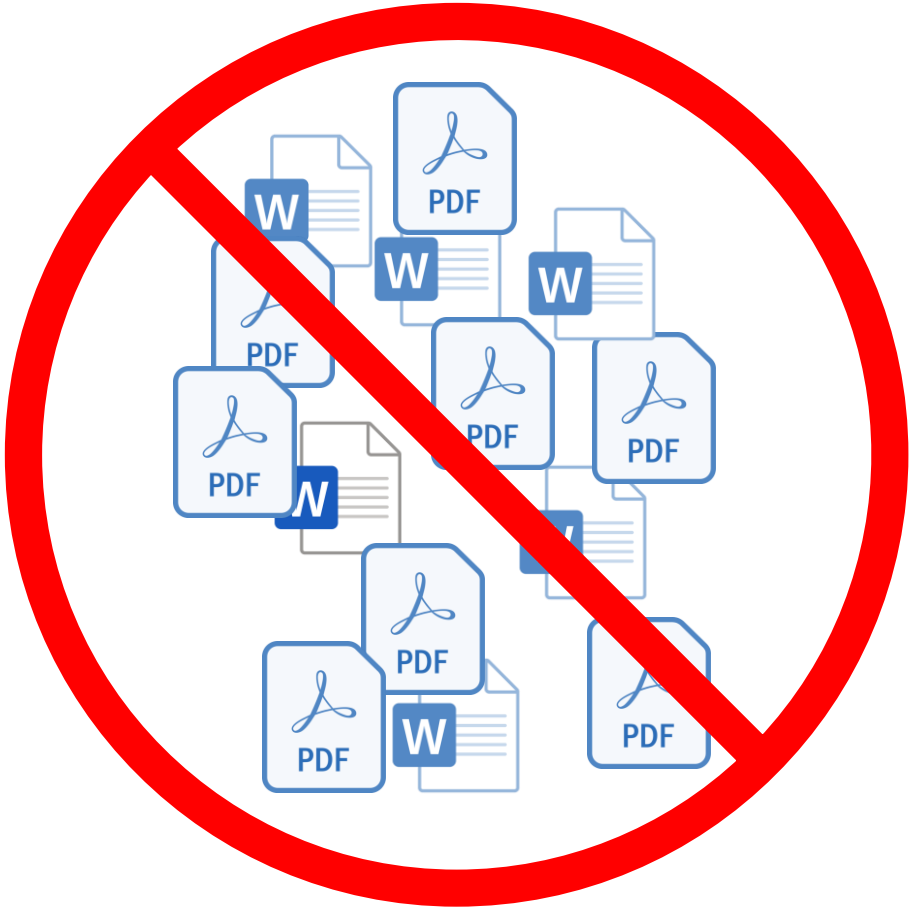
A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process

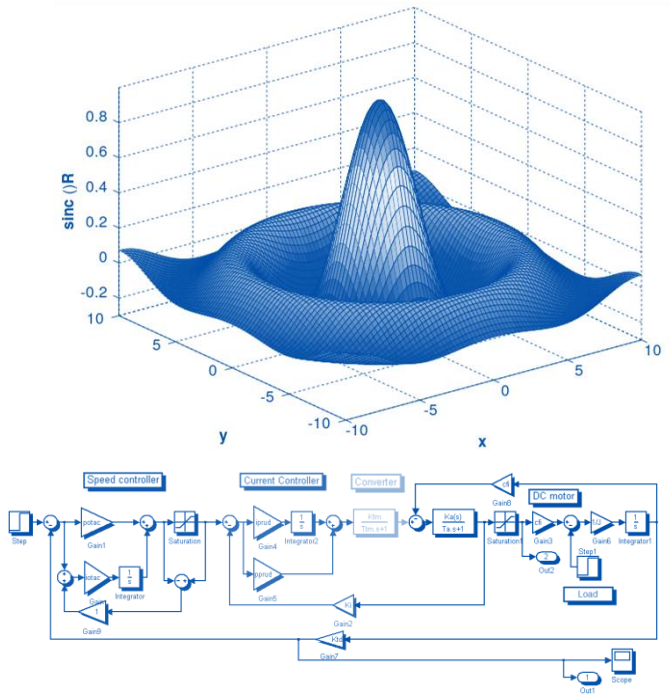
DoD5000.59-M 1998

Much of the confusion in MBSE is the ambiguity in “model”. If everything is a model, everything qualifies as MBSE.

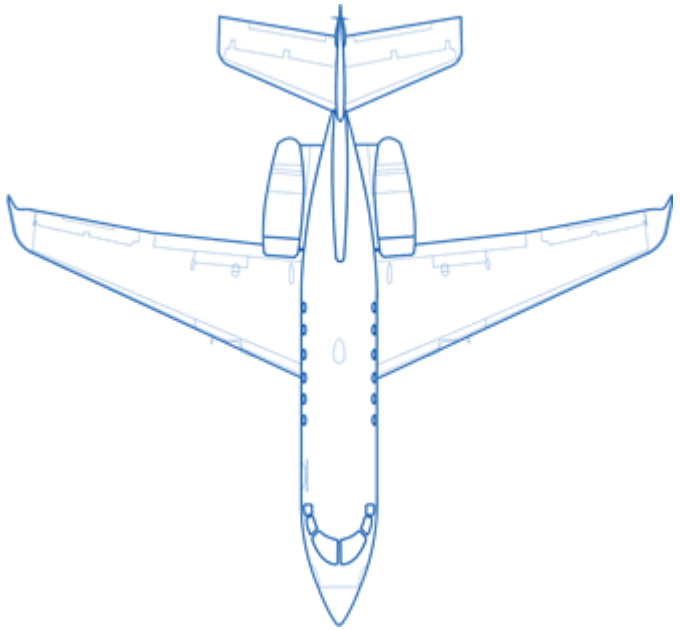
Recognizing Myths and Misconceptions

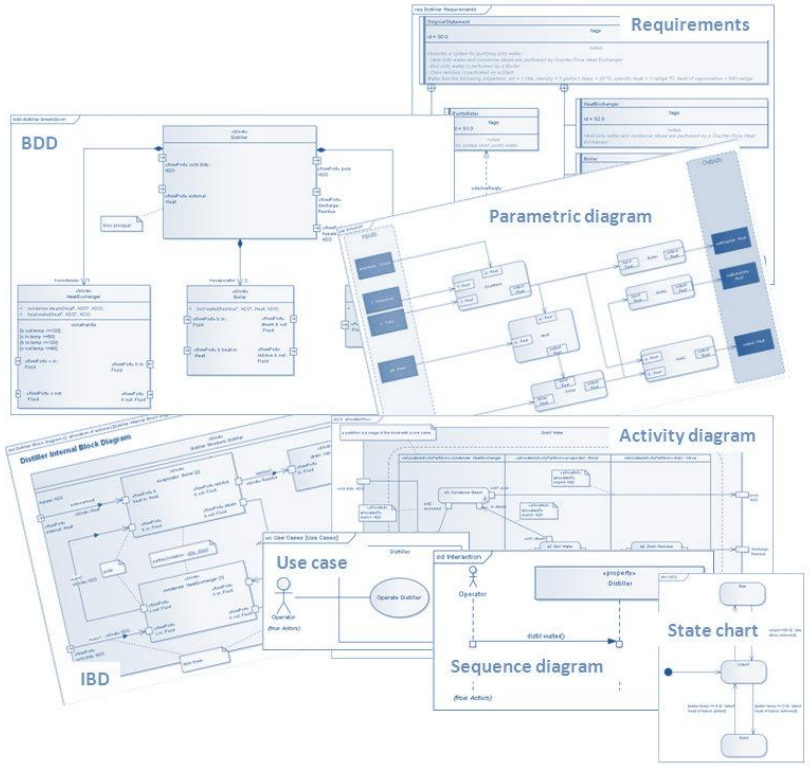
What MBSE Is Not

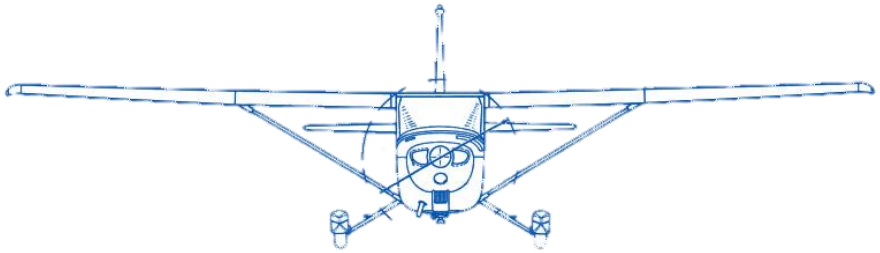


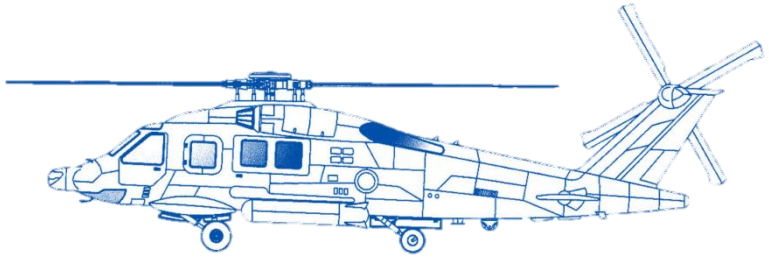


Recognizing the Decoy of Diagram-Based SE



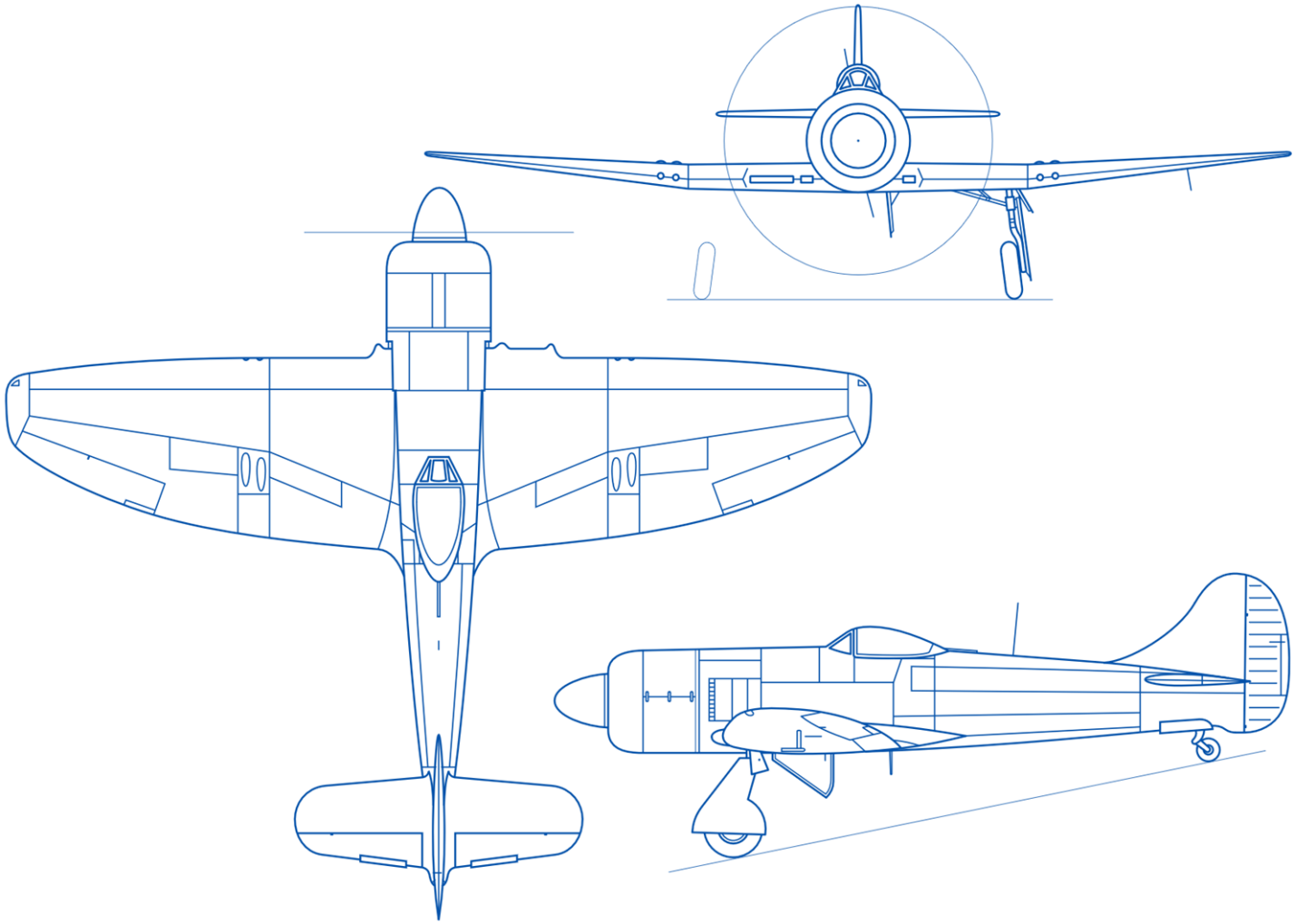






Focusing on Essential Information and Clarity

Look to Data before Visualization



Points

Vectors

Credit: MLWatts. CC0, https://commons.wikimedia.org/w/index.php?curid=21356392

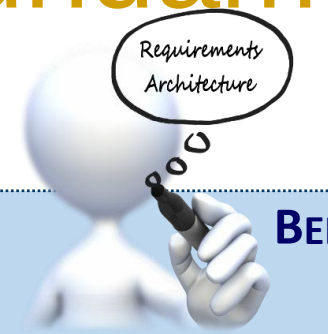
Explicit over Implicit

Clarity over Ambiguity

Authoritative Data over Artifacts

Accuracy || Precision

Focusing on the Fundamental Concepts



PROBLEM

A System's ***WHY***

BEHAVIORAL ARCHITECTURE

A System's ***WHAT***

A System's ***PROOF***

VERIFICATION

A System's ***HOW***

PHYSICAL ARCHITECTURE

ANALYTICAL ARCHITECTURE

A System's ***PHYSICS***

Focusing on the Foundational Concepts

Specifying the Design Envelope and Interfaces

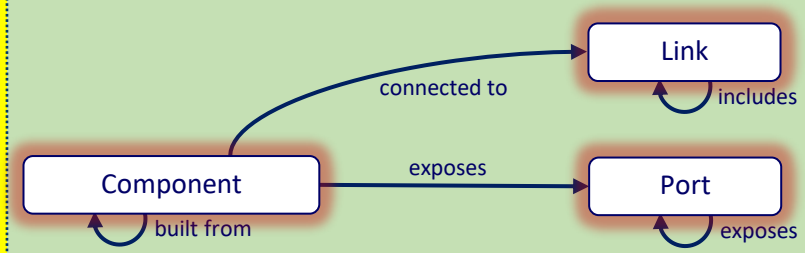
PROBLEM

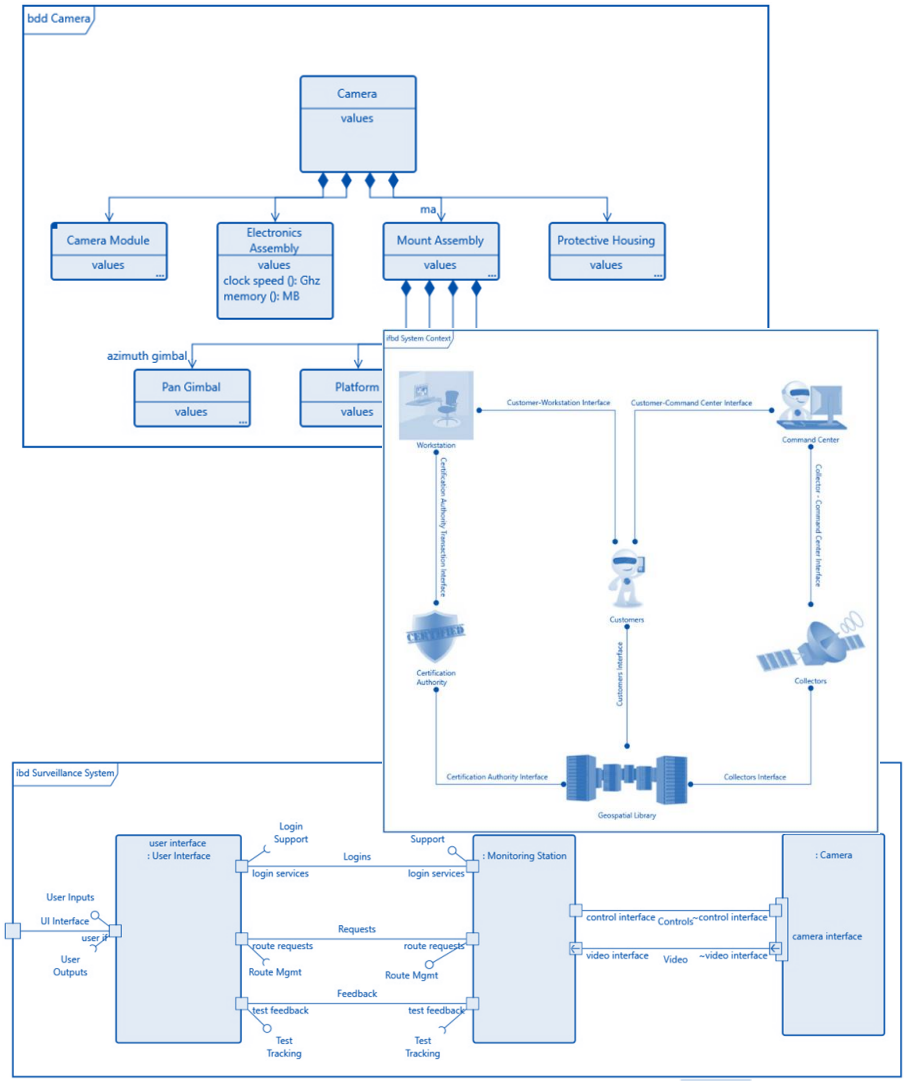
BEHAVIORAL ARCHITECTURE

VERIFICATION

PHYSICAL ARCHITECTURE

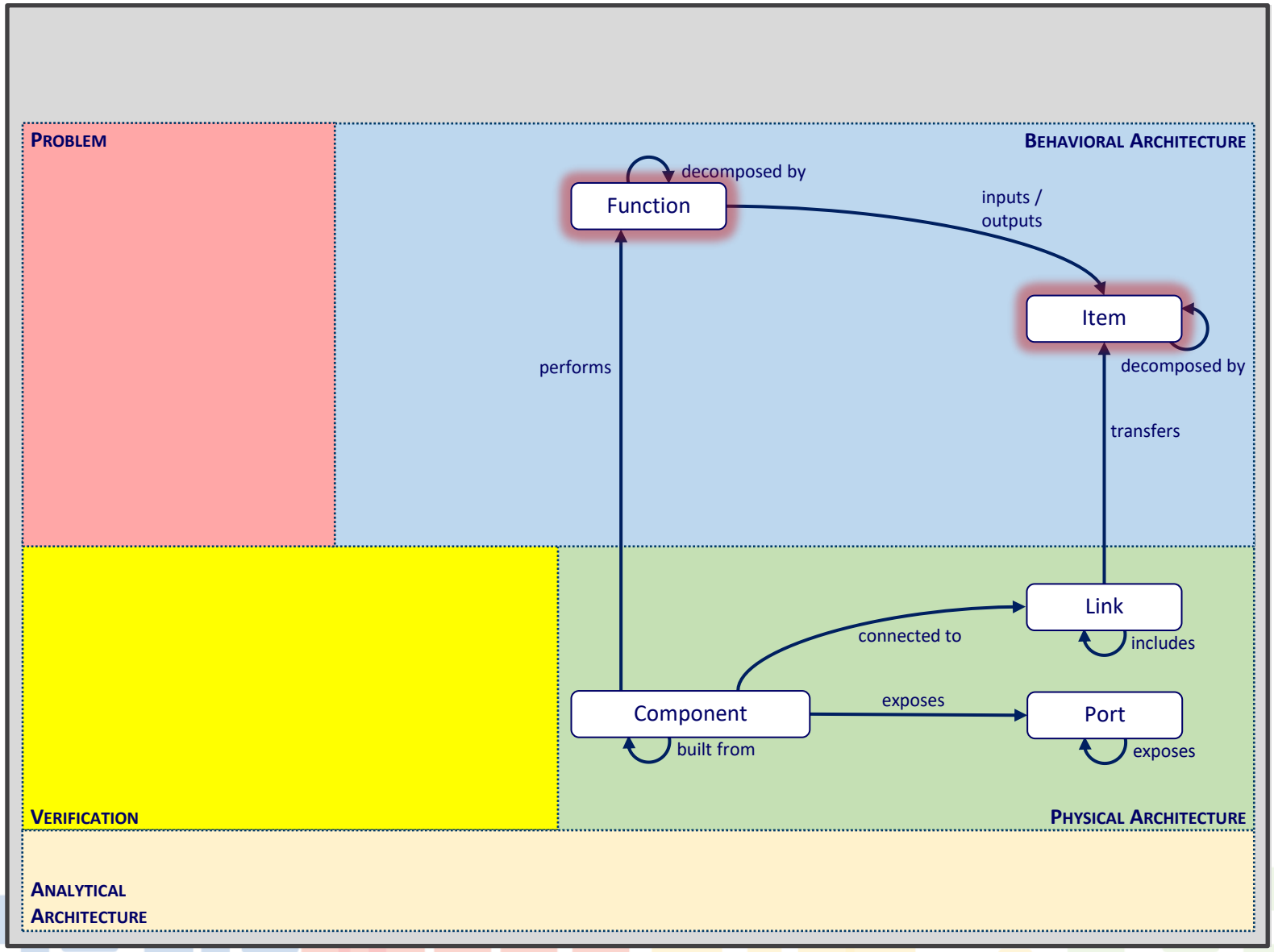
ANALYTICAL ARCHITECTURE

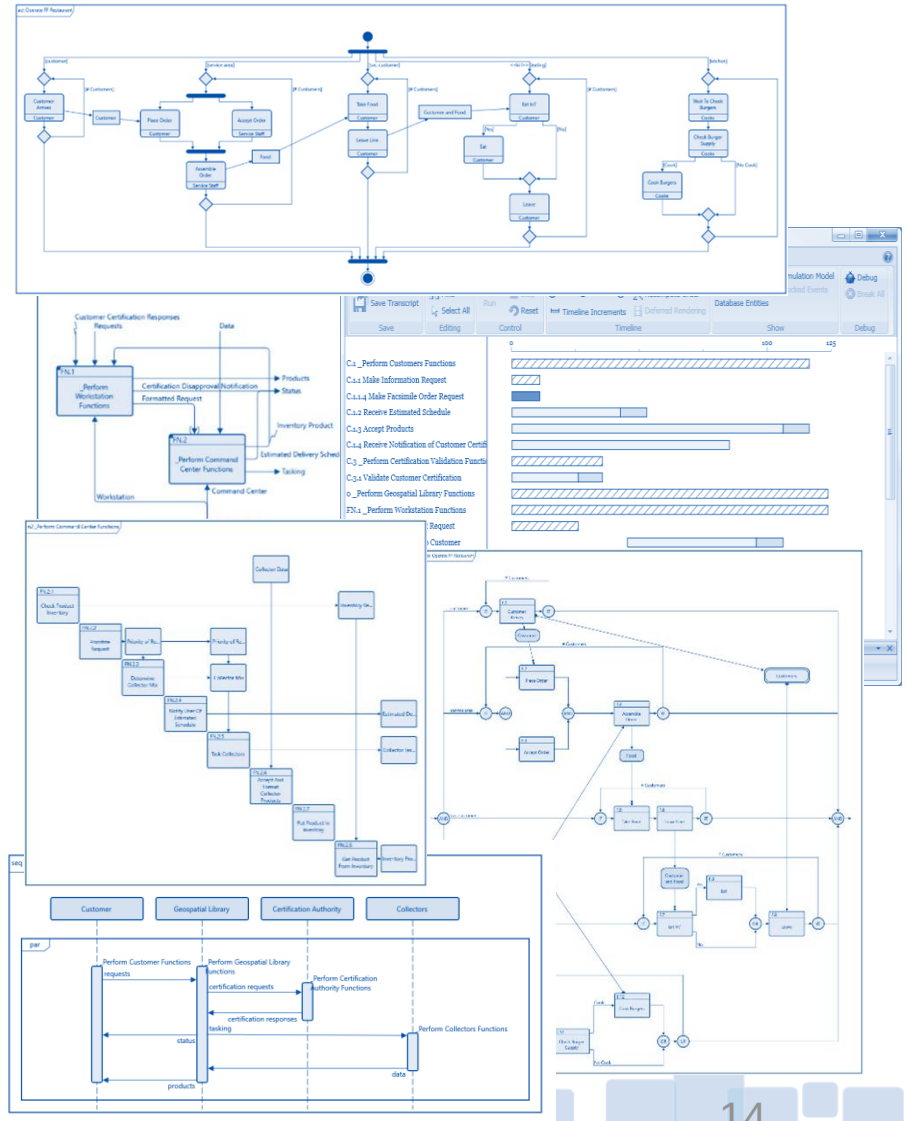




Focusing on the Foundational Concepts

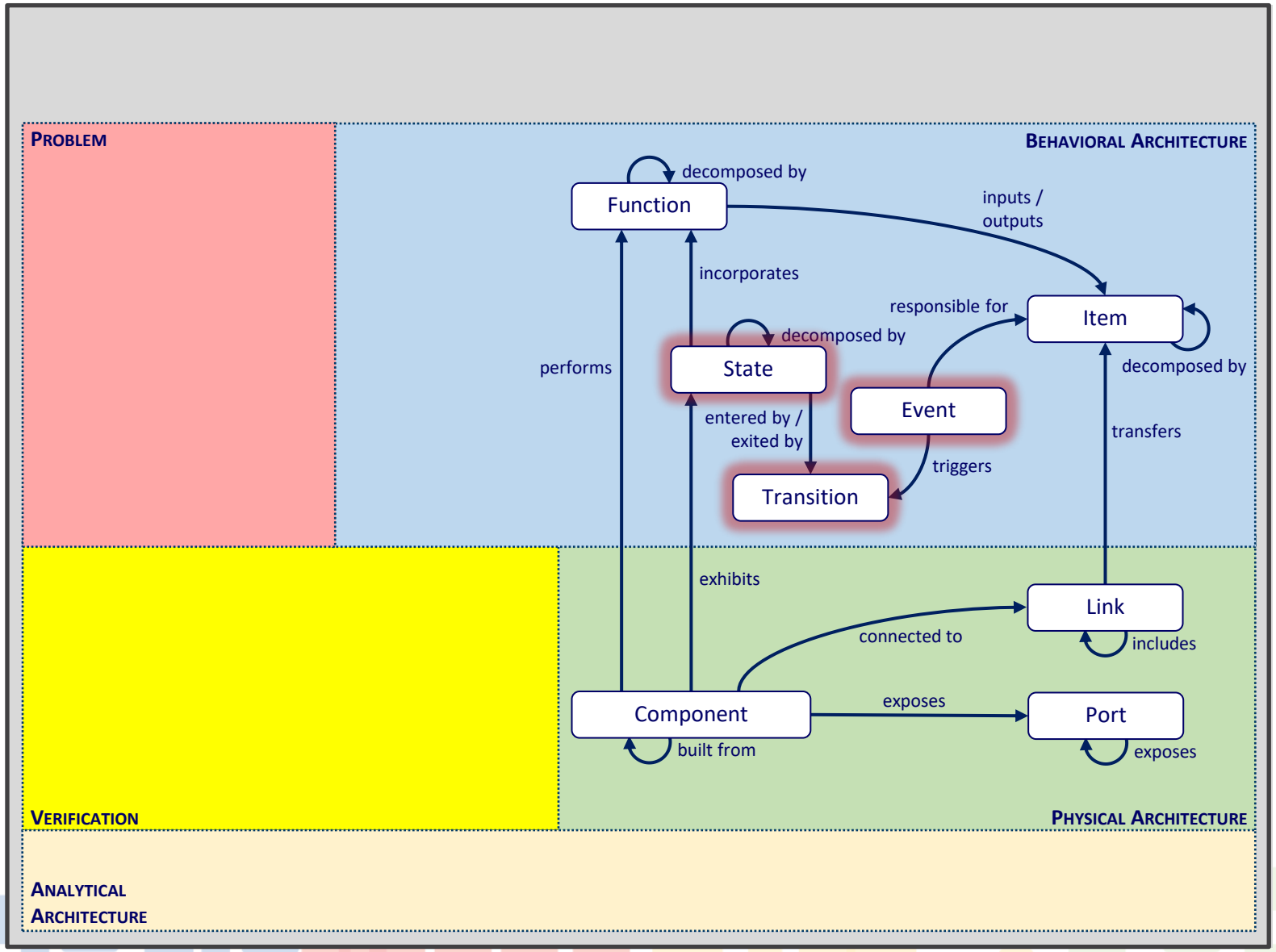
Defining Functions and Exchanges

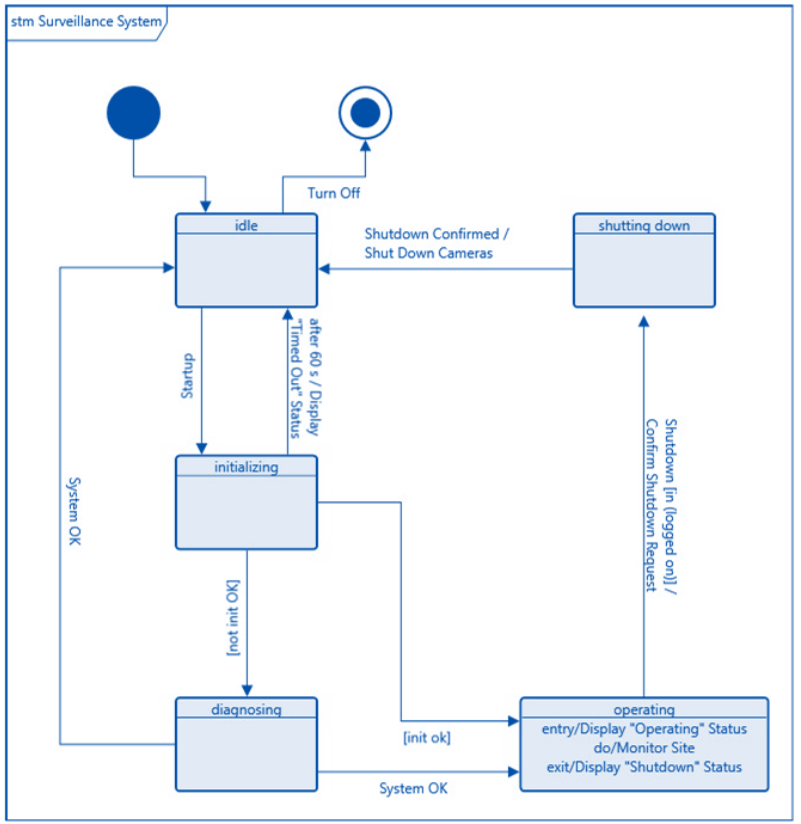




Focusing on the Foundational Concepts

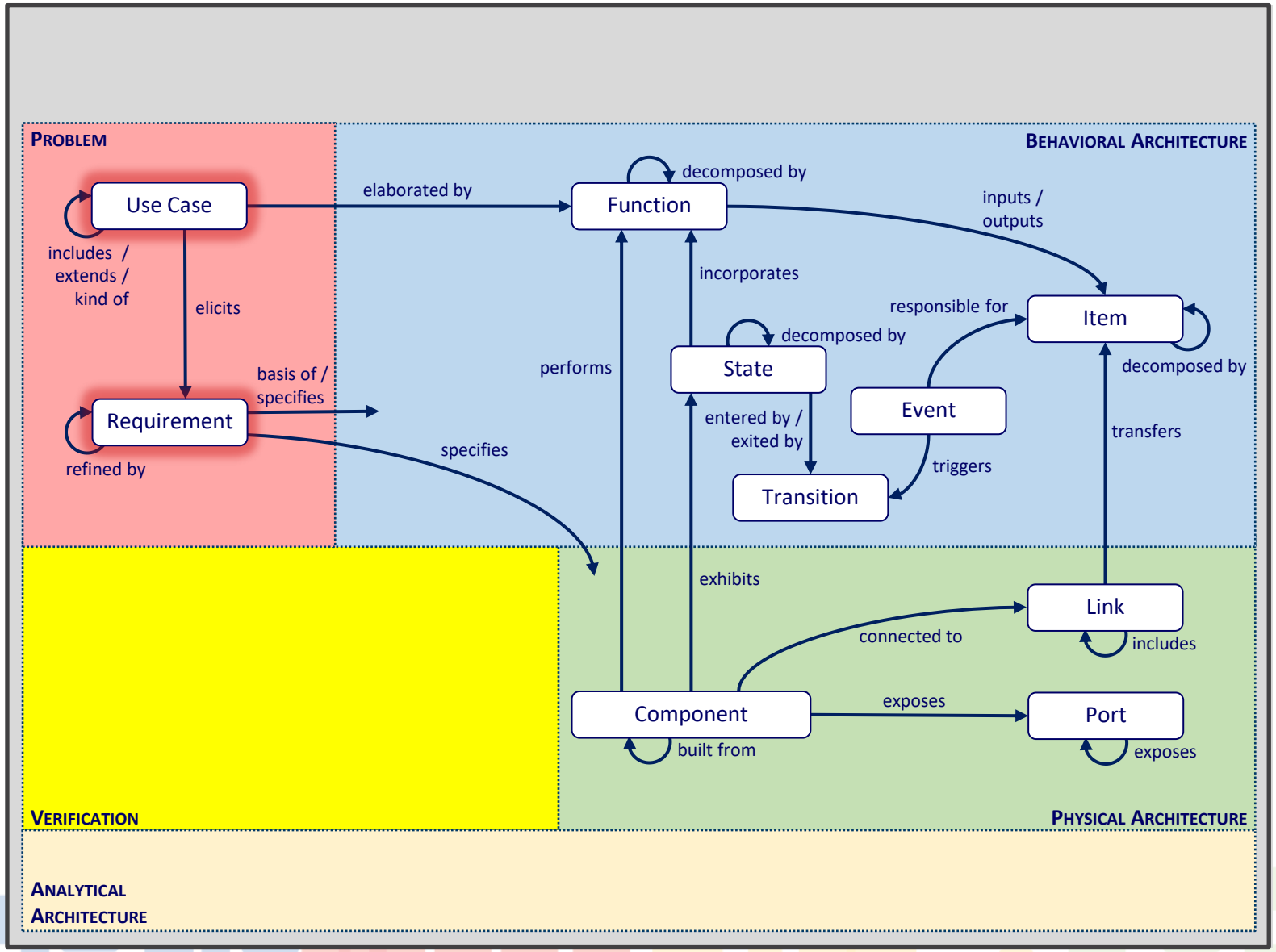
Considering All States

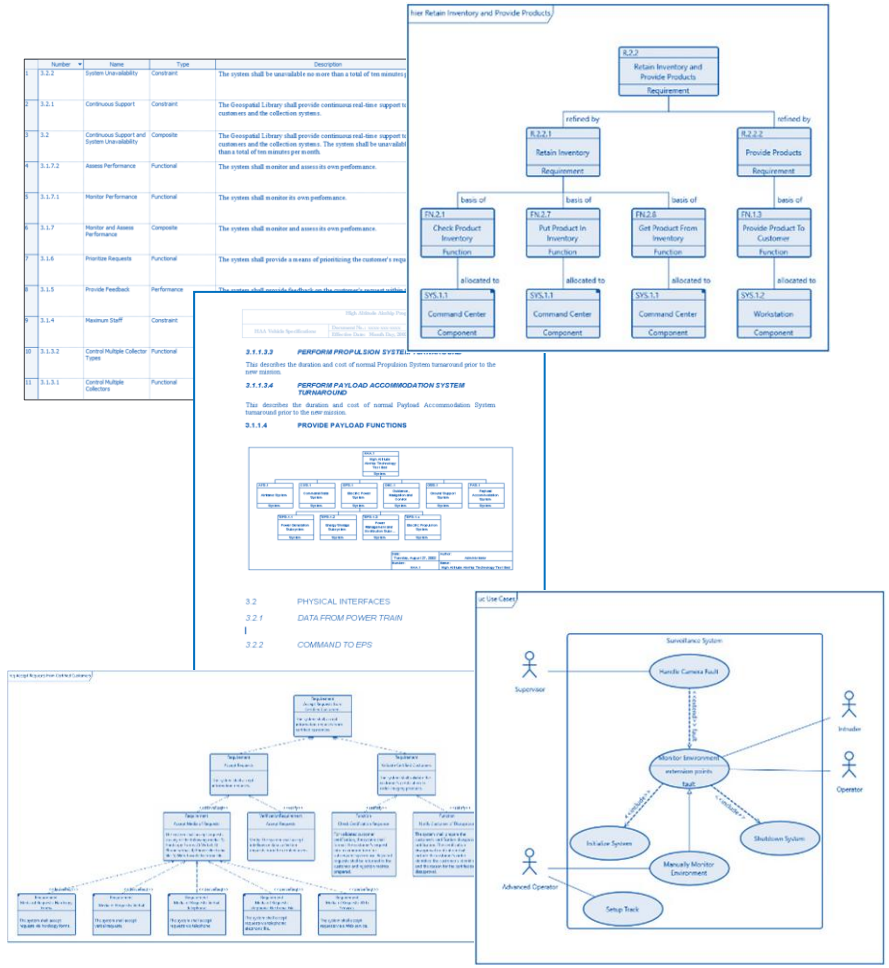




Focusing on the Foundational Concepts

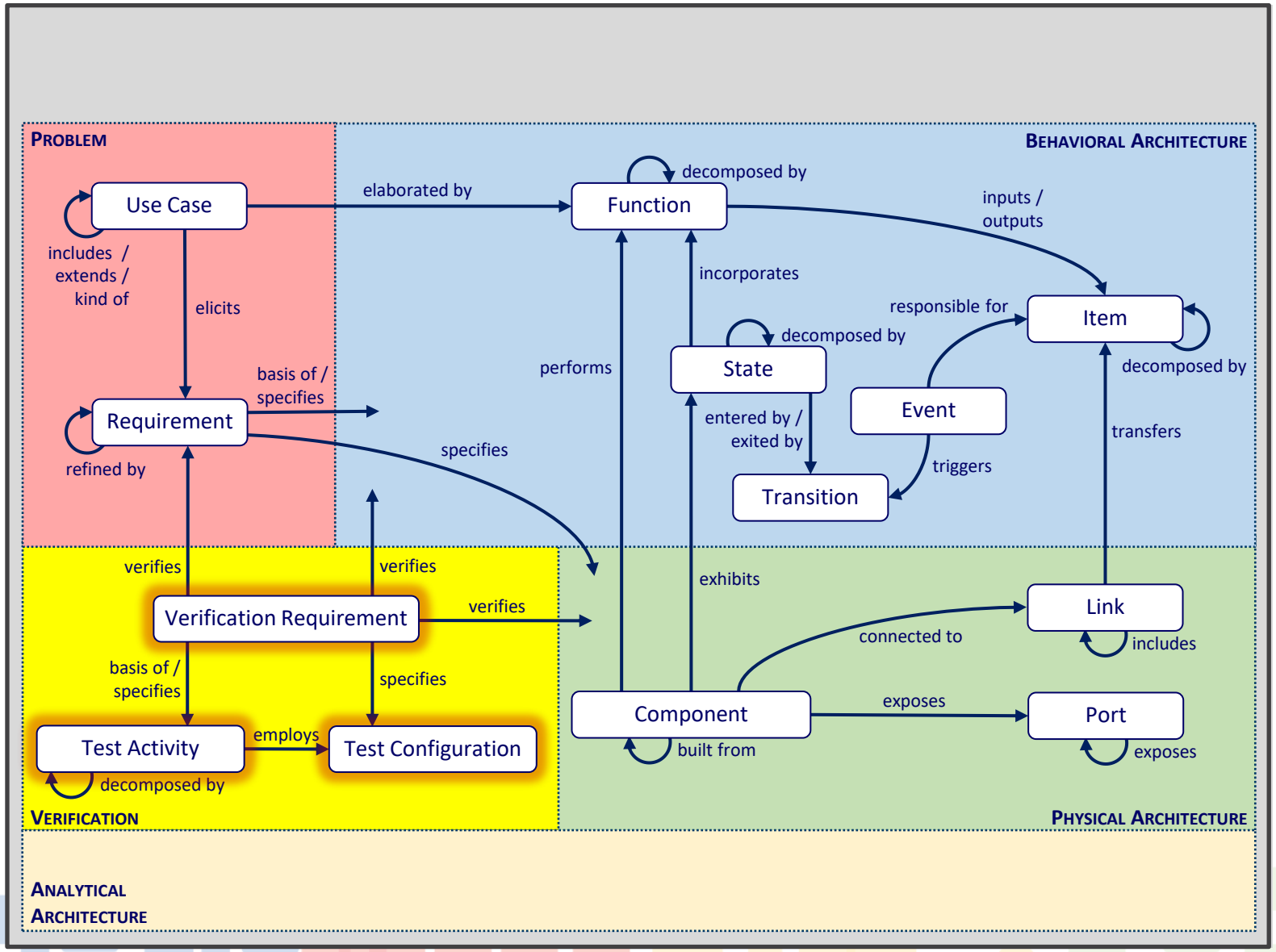
Capturing the Right Problem, Tracing Throughout

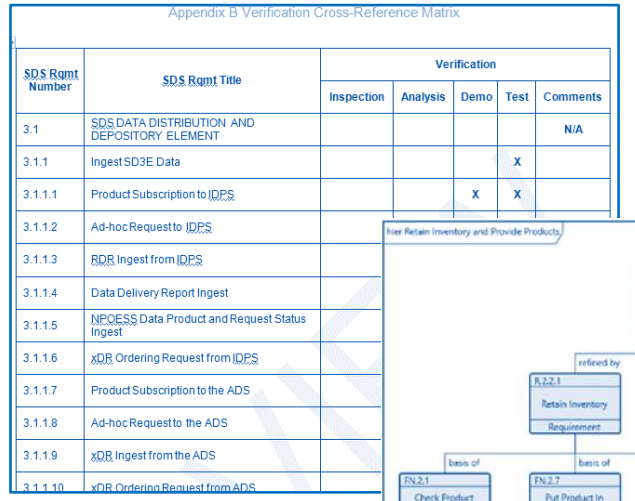




Focusing on the Foundational Concepts

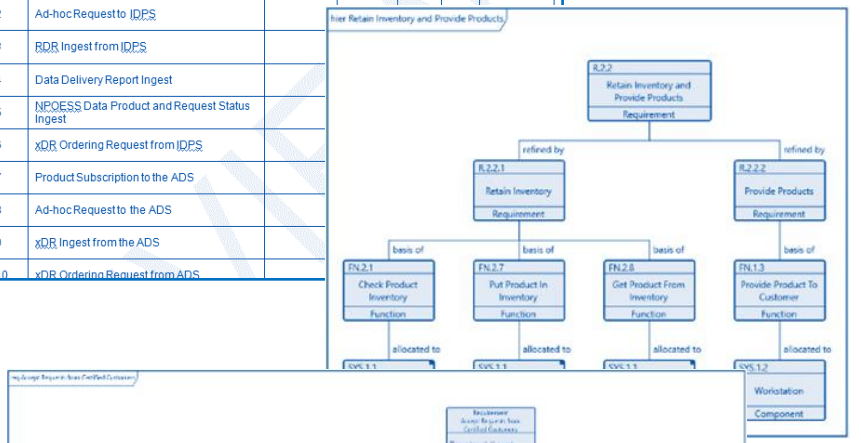
Planning and Tracking Verification

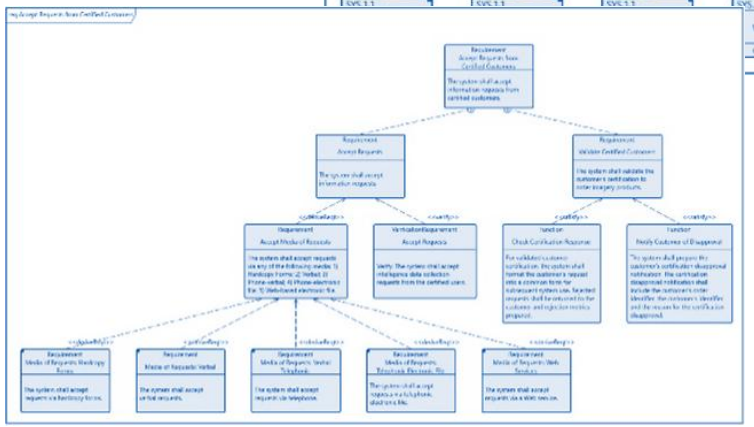




Appendix B Verification Cross-Reference Matrix

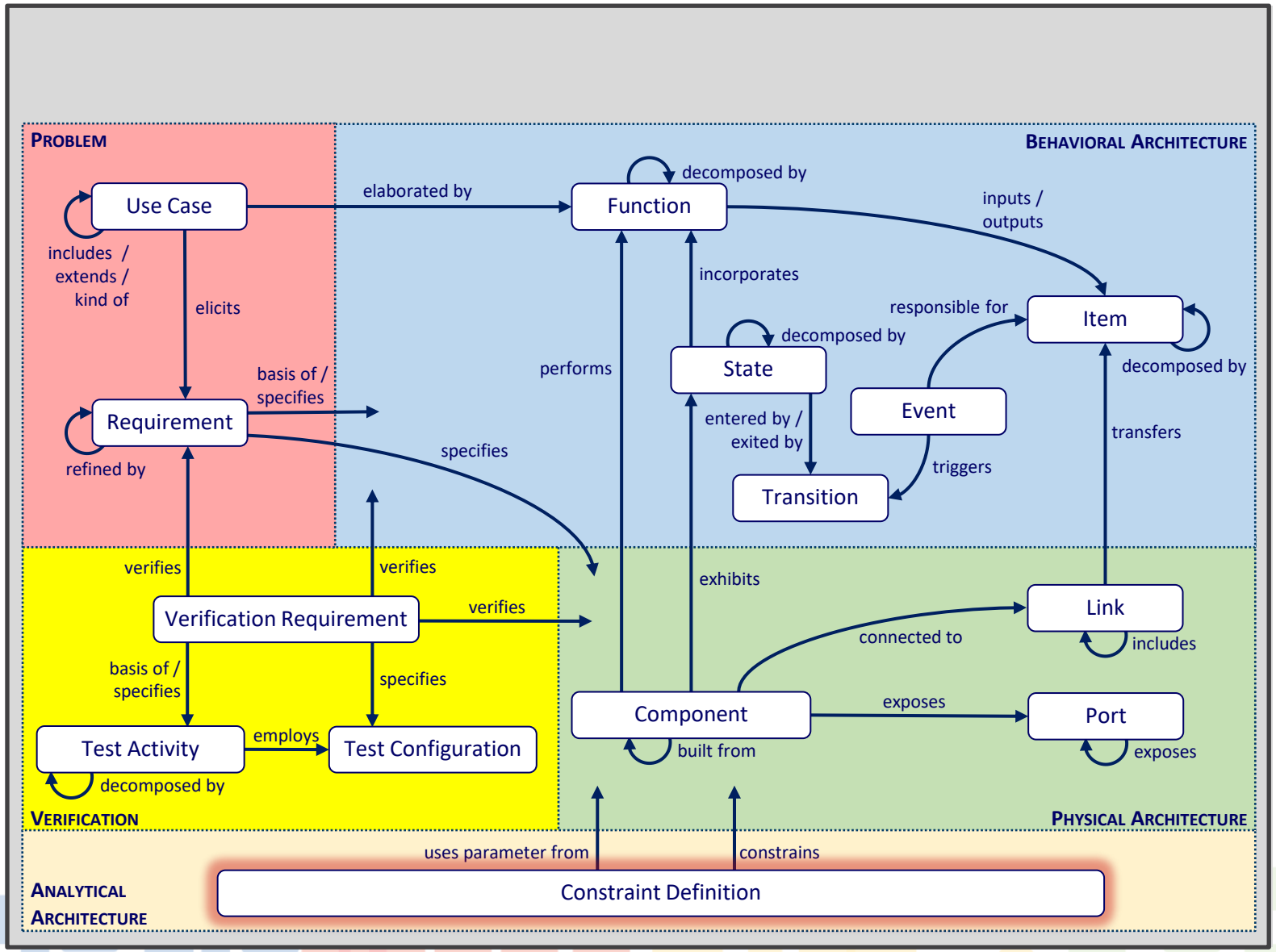
SDS Rqmt Number	SDS Rqmt Title	Verification				
		Inspection	Analysis	Demo	Test	Comments
3.1	SDS DATA DISTRIBUTION AND DEPOSITORY ELEMENT					N/A
3.1.1	Ingest SD3E Data				X	
3.1.1.1	Product Subscription to IDPS			X	X	
3.1.1.2	Ad-hoc Request to IDPS					
3.1.1.3	RDR Ingest from IDPS					
3.1.1.4	Data Delivery Report Ingest					
3.1.1.5	NPOESS Data Product and Request Status Ingest					
3.1.1.6	xDR Ordering Request from IDPS					
3.1.1.7	Product Subscription to the ADS					
3.1.1.8	Ad-hoc Request to the ADS					
3.1.1.9	xDR Ingest from the ADS					
3.1.1.10	xDR Ordering Request from ADS					

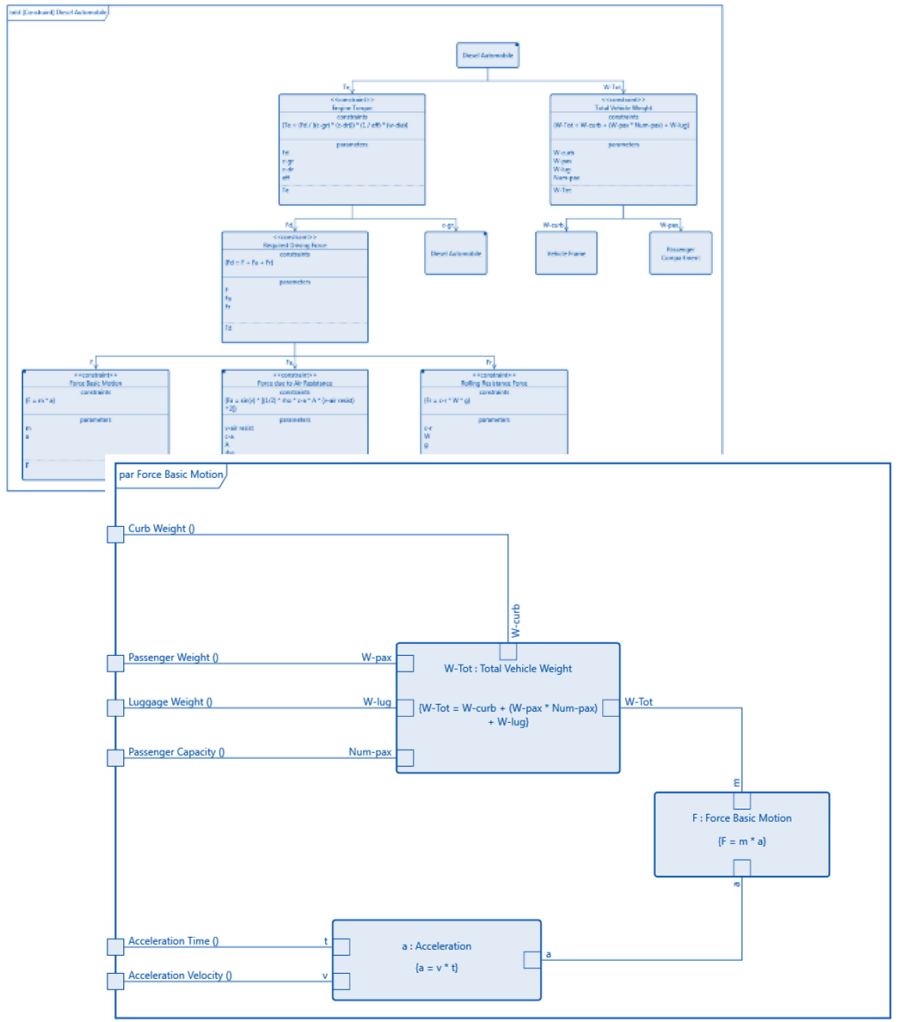




Focusing on the Foundational Concepts

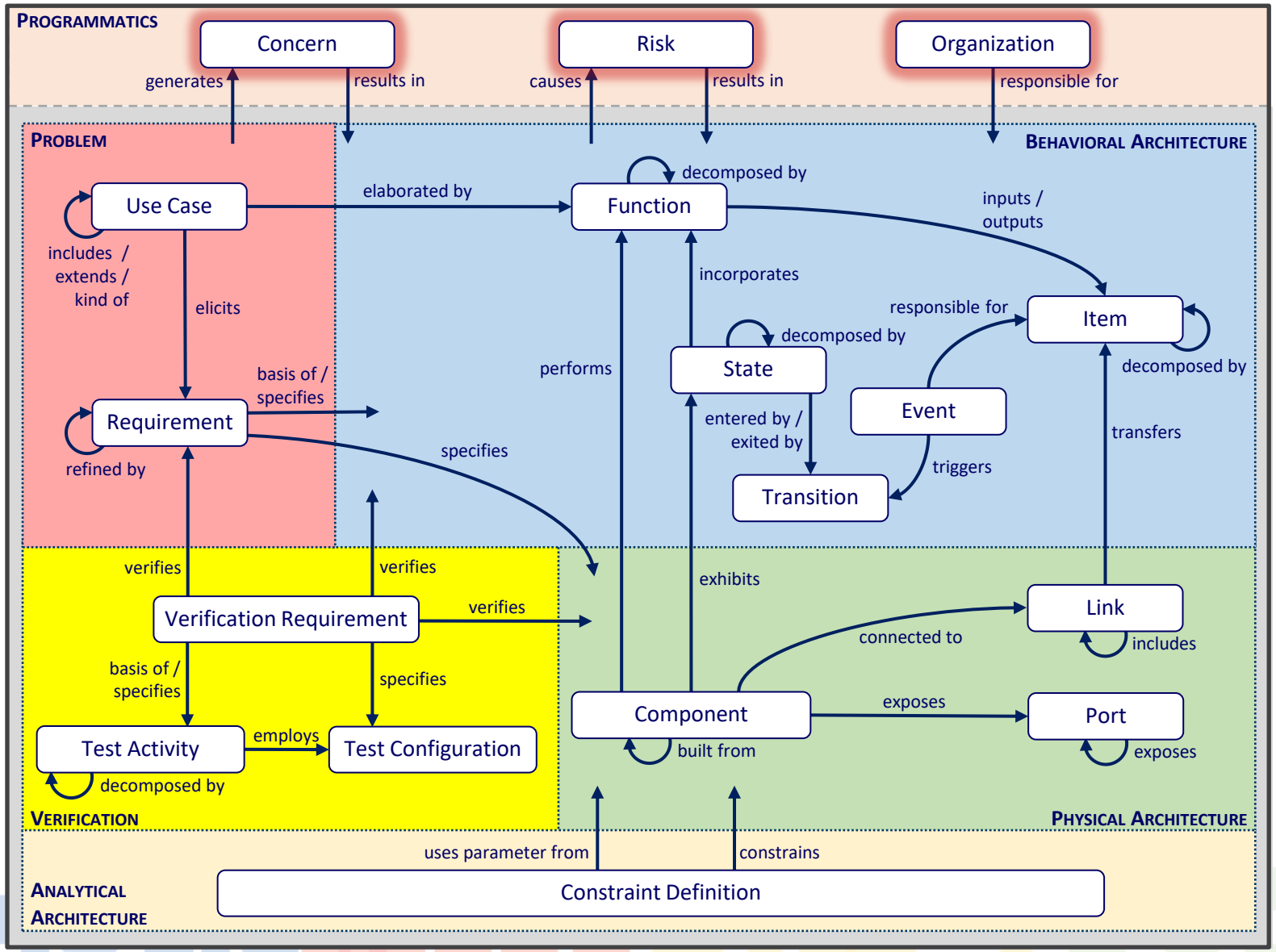
Engineering with Rigor

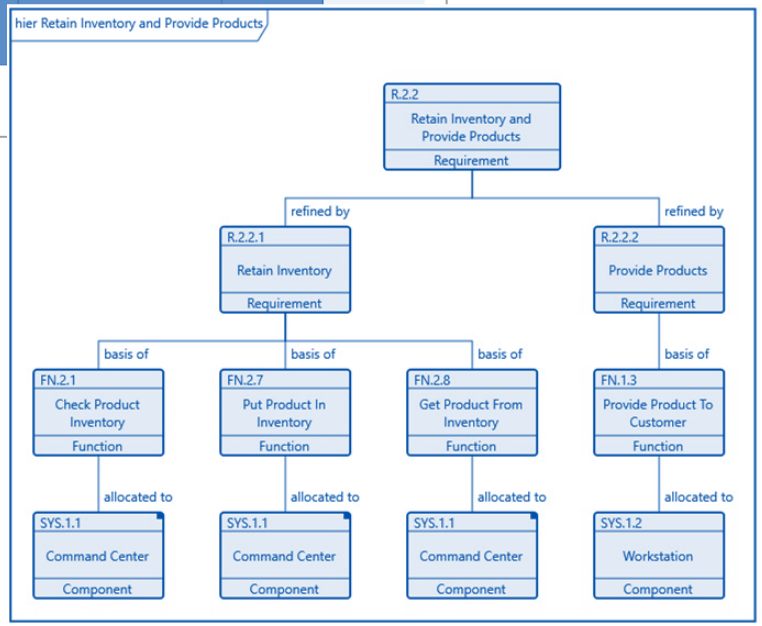




Focusing on the Foundational Concepts

Capturing the Journey

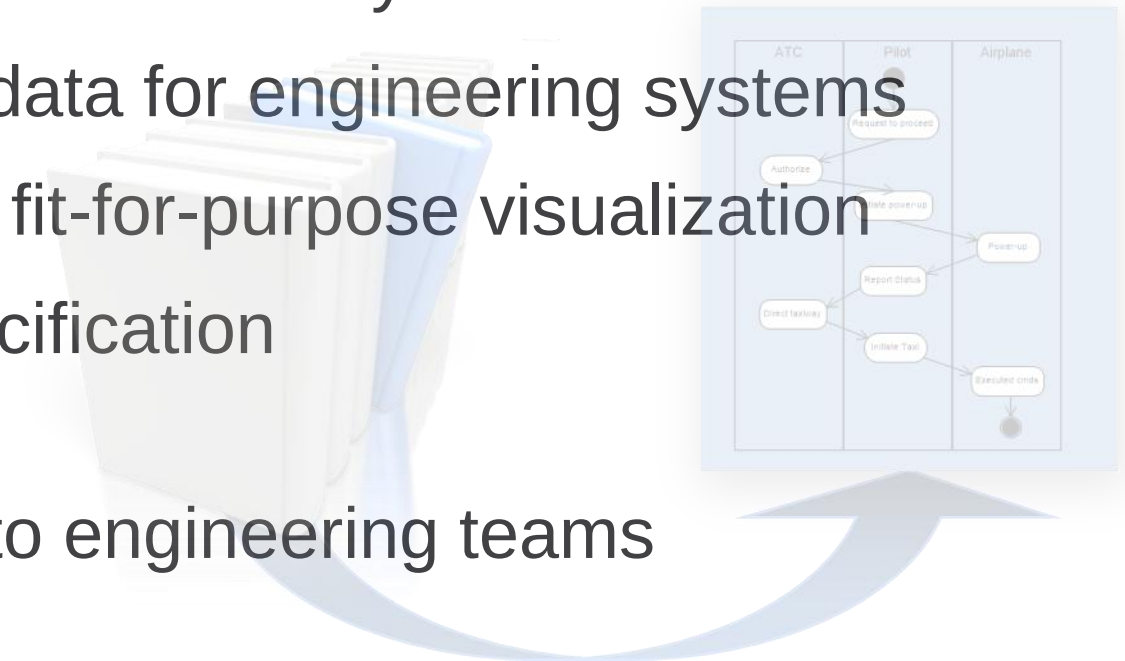




Expressing the Fundamentals of MBSE

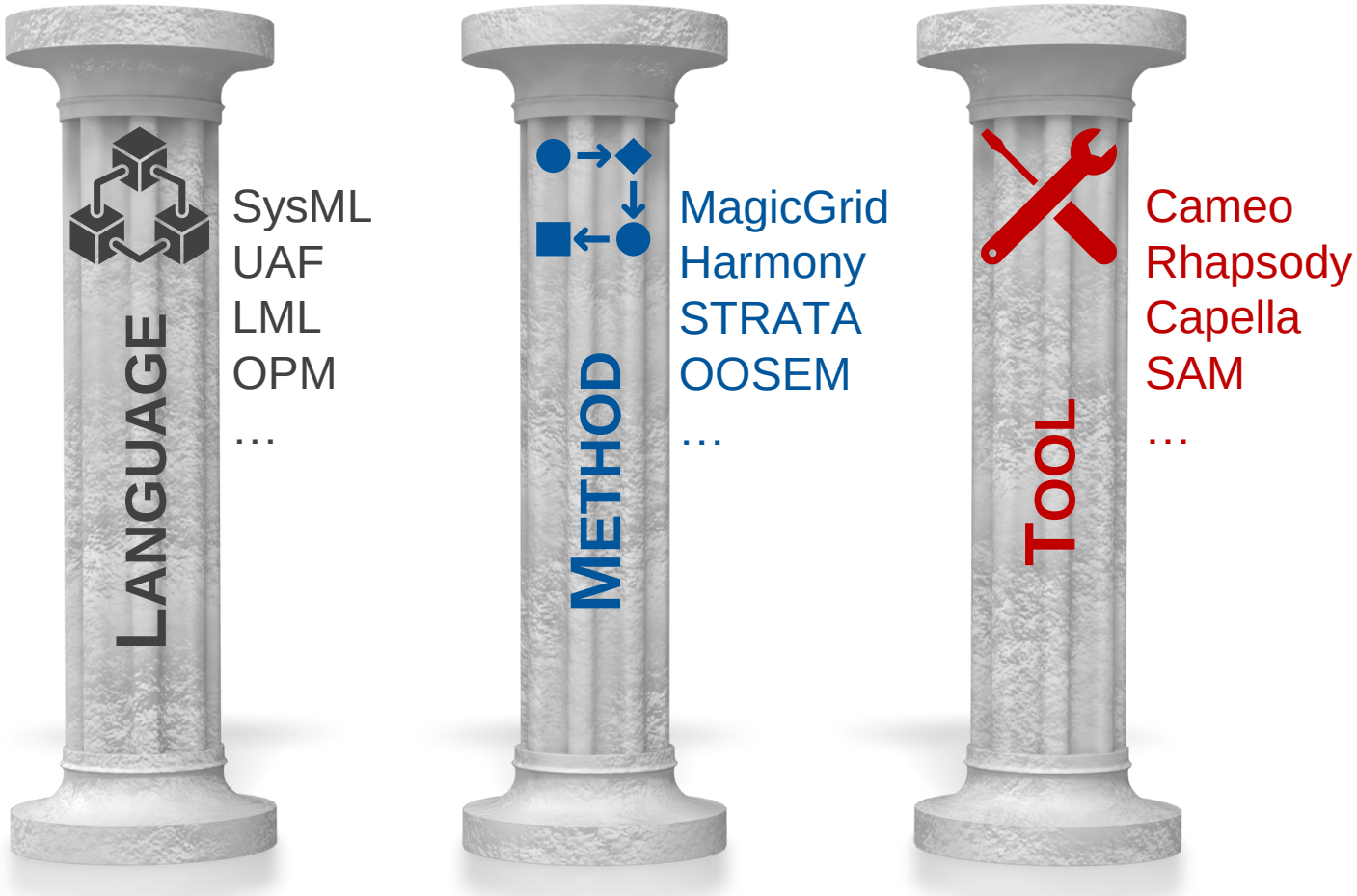
Model-Based Systems Engineering is about…

- Making system architectural and analytical models **explicit**, **coherent**, **consistent**, and **actionable** through the power of digital
- Leveraging models for communication and analysis
- Developing and using authoritative data for engineering systems
- Freeing data from artifacts enabling fit-for-purpose visualization
- Ensuring consistent design and specification (when done well)
- Providing an explicit system model to engineering teams



Understanding “The Three Pillars of MBSE”

Awareness with Caution



Defining the Purpose of Your Model

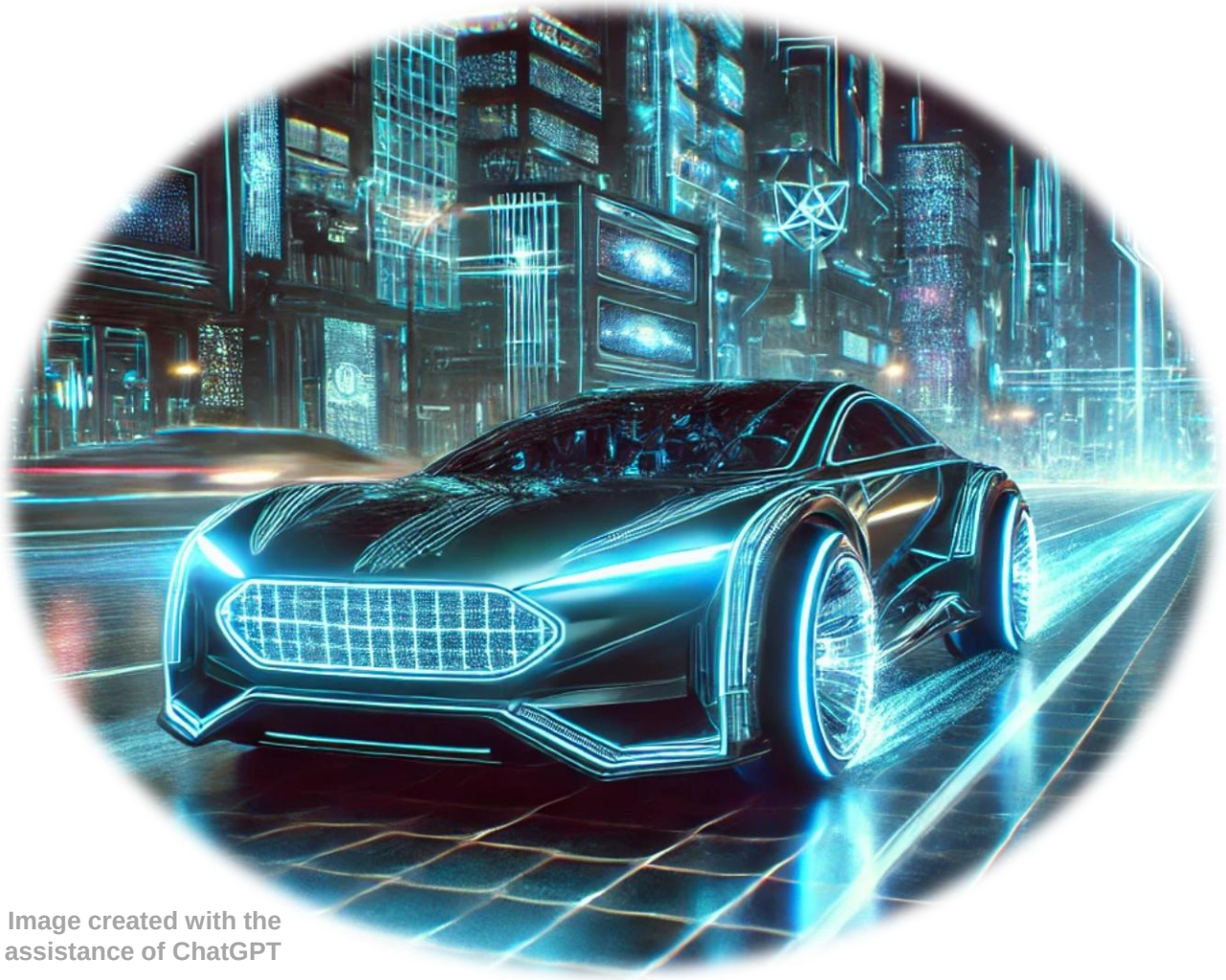
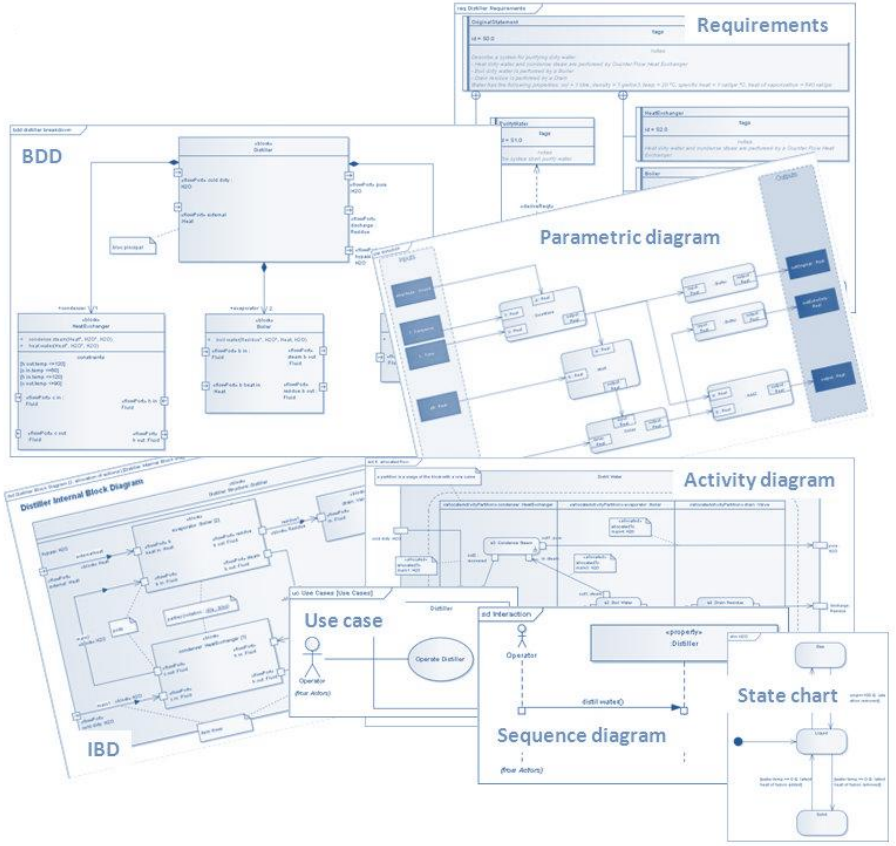
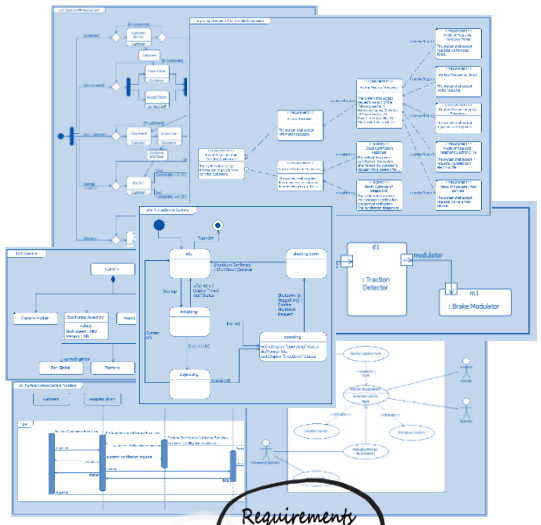


Image created with the assistance of ChatGPT

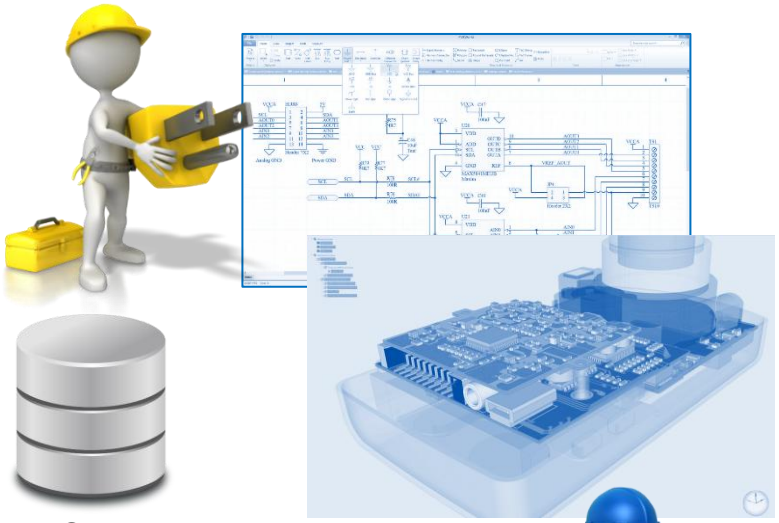


Avoiding the Trap of Silos of Excellence

Disconnected Engineering in a Complex World



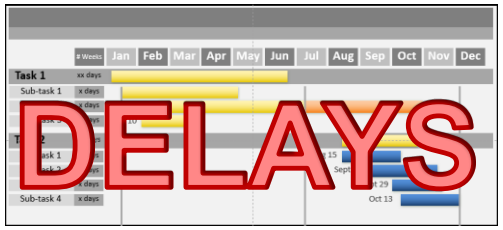
MBSE



ECAD

ALM

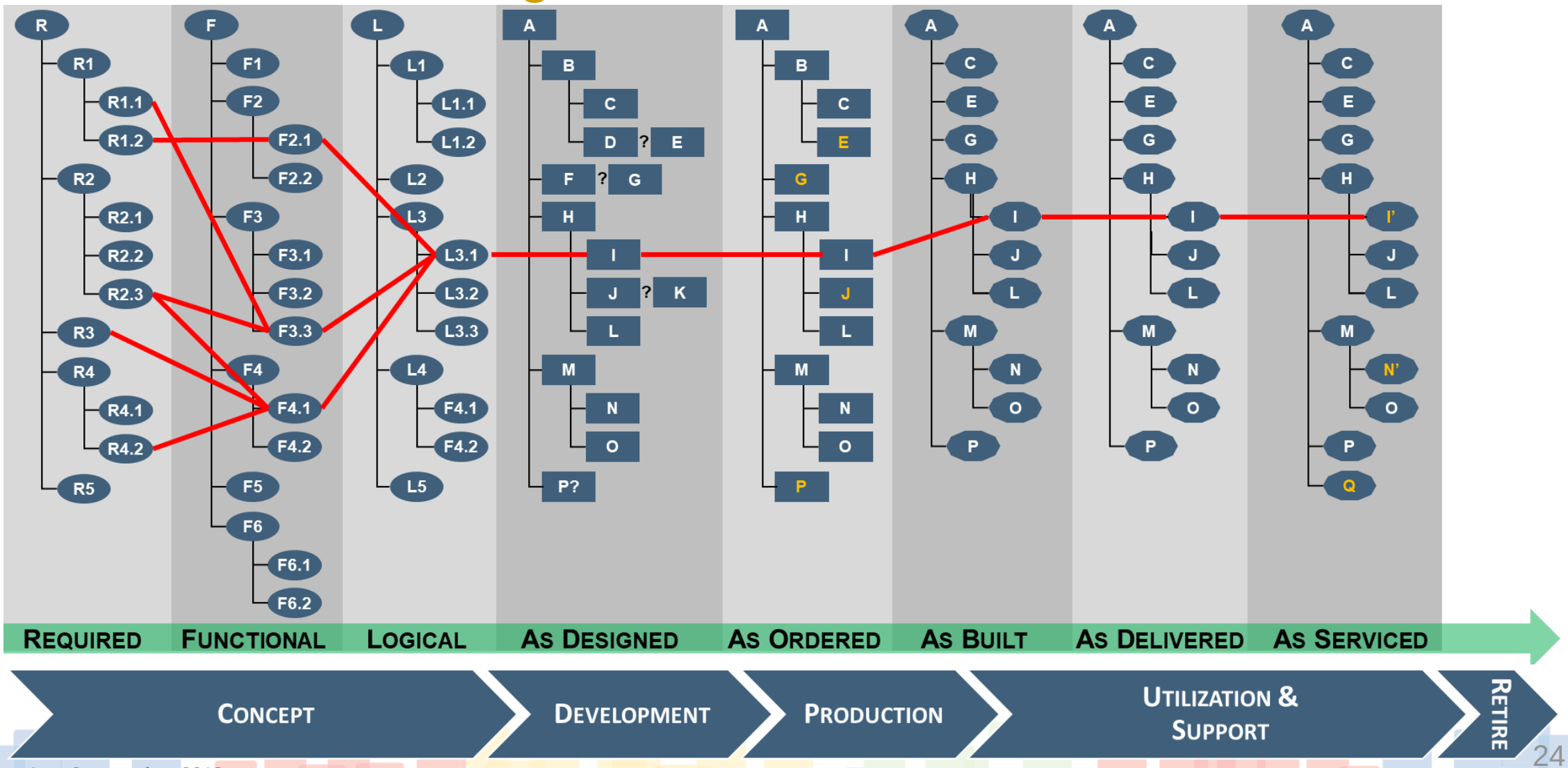
MCAD



CONCEPT | DEVELOPMENT | PRODUCTION

Maintaining an Unbroken Thread of Traceability

The Power of the Digital Thread



Adapted from Aras Corporation, 2018.

Leveraging the Power of Digital

A "Smart" Digital Twin Connecting Design and Operation

Credit: Sumit Awinash, Creative Commons 4.0

A digital twin is virtual representations of real-world entities and processes, synchronized at a specified frequency and fidelity

Digital Twin Consortium

Connecting the Engineering Lifecycle

The Authoritative Source of Truth

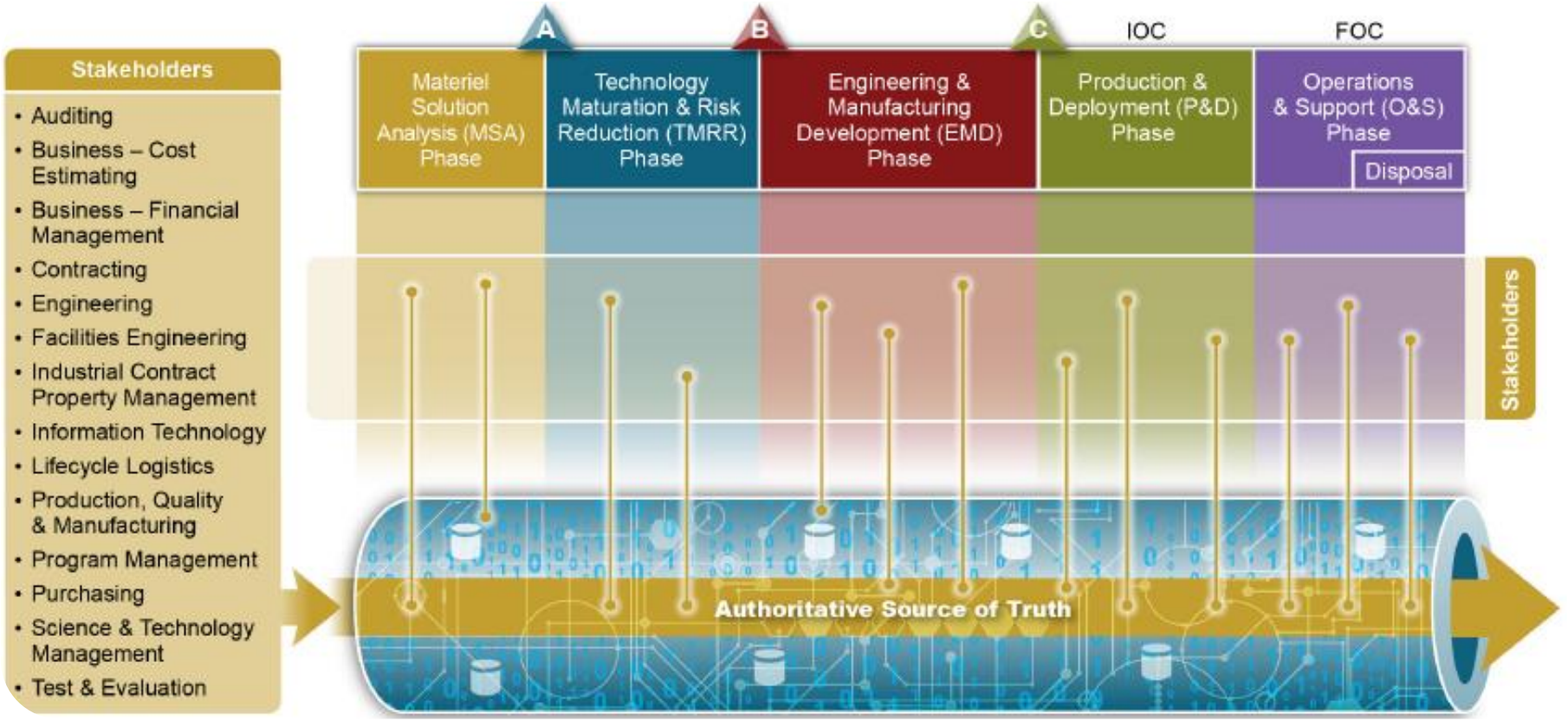


Image Credit: US Department of Defense, 2018

An integrated approach using authoritative data and models as a continuum across disciplines and across the lifecycle

Department of Defense
Digital Engineering Strategy

Relating the Key Concepts

The Foundations of DE and Our Digital Transformation

Digital Engineering *a critical enabler for the modern engineering enterprise*

MBSE

connective tissue of the Digital Engineering environment

Systems Engineering

technical connective tissue of the project team

Data

oxygen fueling 21st century engineering and operations

Delving Deeper into Engineering Digitally

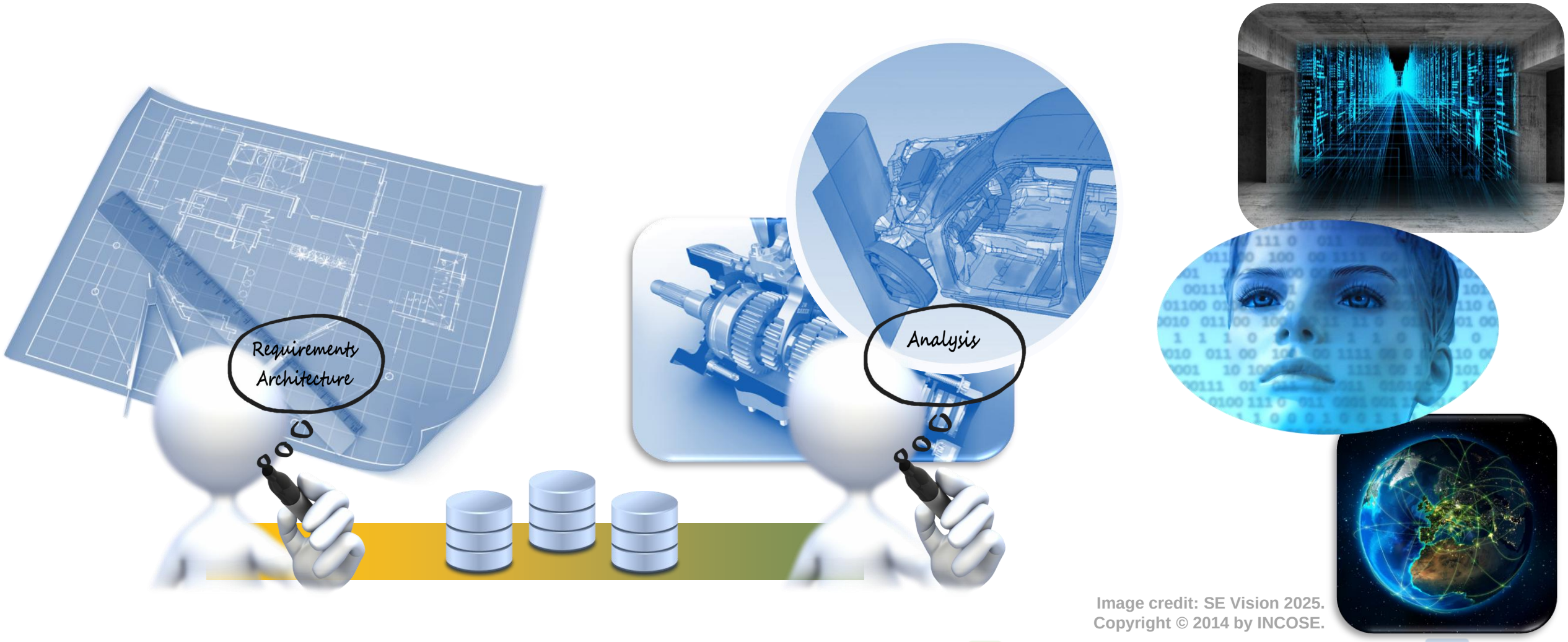
Critical ideas, enablers, challenges, and opportunities

Engineering Does Not Require All Data at All Times

Right Data, Right Abstraction, Right Place, Right Time, Right Presentation

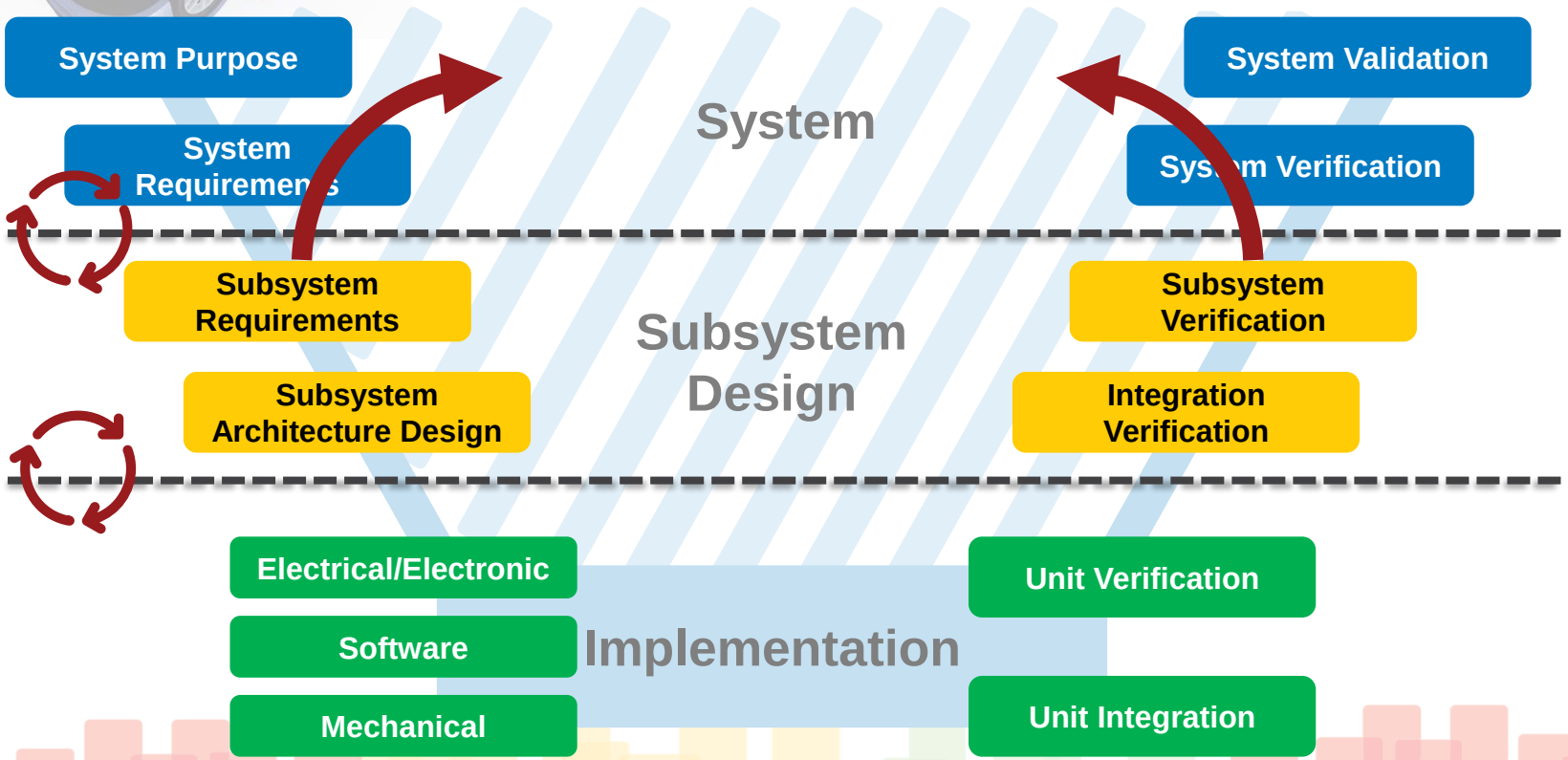
Immersing in Design and Analysis

Information-Aware over Data-Seeking, Hands-on over Conduits

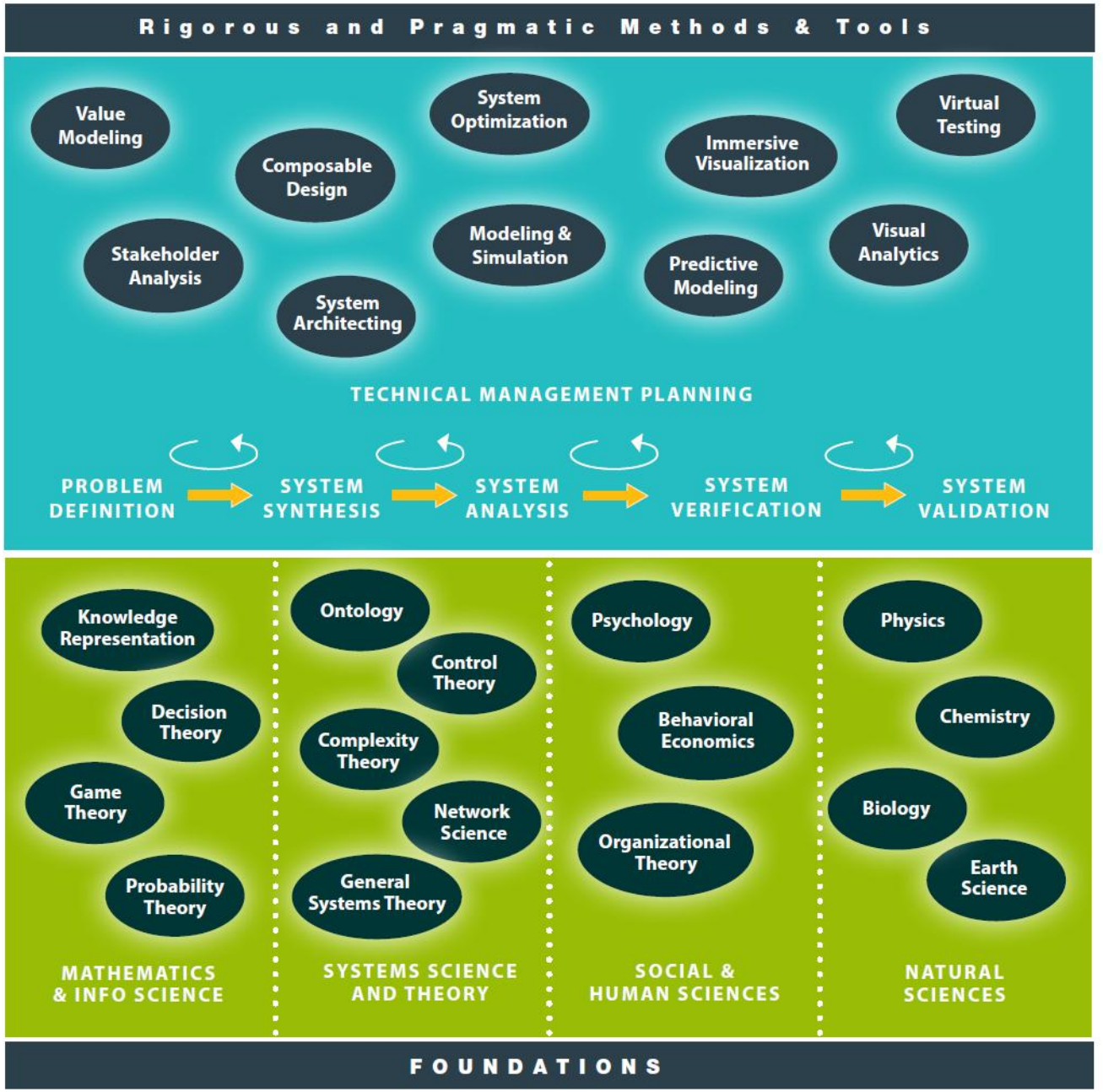


Tightening the (Systems) Engineering V

Avoiding Defect Injection, Accelerating Defect Detection

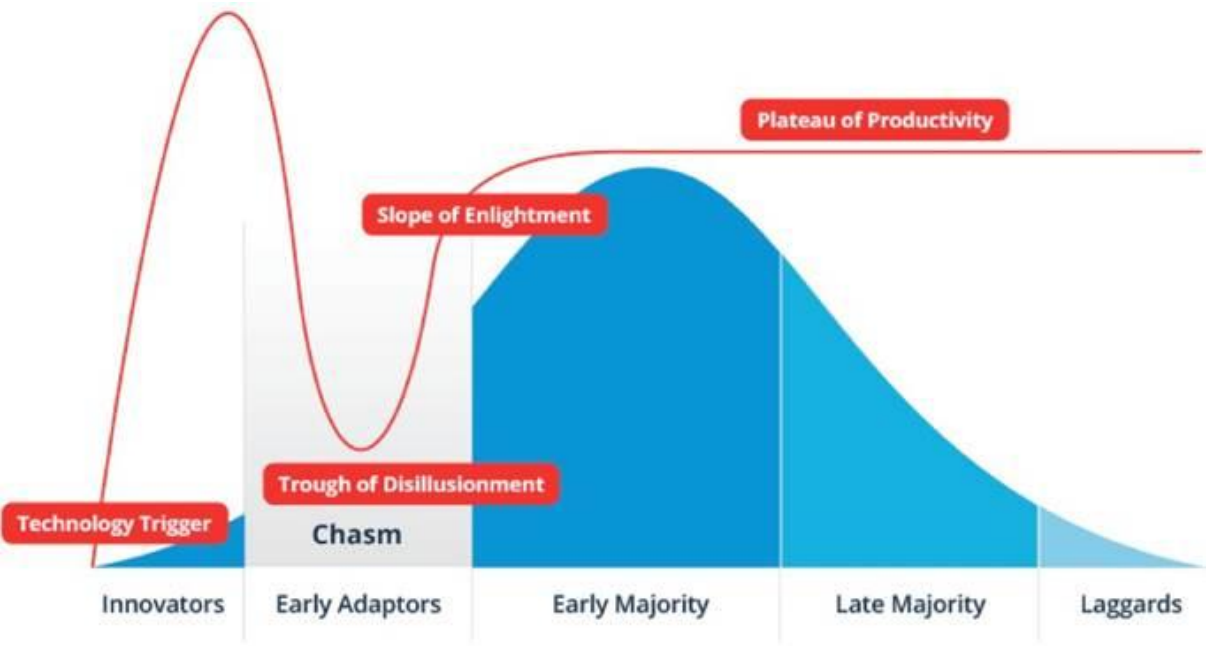


Establishing a Connected Foundation of Theory and Science



Looking beyond Marketing Hype

Assessing and Benchmarking Capability



Solution	(1) Initial	(2) Managed	(3) Defined	(4) Qualitative	(5) Optimizing
Product engineering	**Uncontrolled**	**Controlled Documents**	**Isolated models**	**Enterprise Integration**	**Continous Engineering**
System Architecture Modeling *Product architecture definition*	PPT in docs	Disconnected Visio diagrams	Standalone SysML with simulations	Fine-grained integrated system architecture	Continuous integration via PLM-based architecture drives closed-loop MBDC
Planned Product Variability *PLE/Configuration/Variation*	None	Variation documents & spreadsheets	Disconnected variation rules	PLM Integrated variation rules	PLM variation definition drive architecture decisions
Reliability & System Safety Analysis *Technical Risk (RAMS)*	Risk documents & spreadsheets	Combined Risk Mgmt plans with manual RAMS artifacts (FMEA)	Disconnected RAMS tools output artifacts (FMECA..)	RAMS analysis tools integrated with product architecture via PLM	Integrated RAMS, continous risk assessment, alarms, dashboards..
Cross domain services					
System Definition & Design Integration *Logical modeling & Interface mgmt*	ICD & logical description documents	Managed interfaces & logical hierarchy	SE artifacts linked to Logical models & Std interface libraries	Integrated fine-grained logical arch with interfaces	Logical architecture carries across domains. Interfaces everywhere
Integrated services					
Feature Engineering *Feature/Functional Modeling*	Feature/Functional description docs	Functional hierarchy	Isolated functional behavior models	Integrated fine-grained functional modeling	Functional arch with allocations & traceability
Parameter/Target Mgmt *Characteristic/Targets/TPM*	Uncontrolled Excel/Docs	Controlled spreadsheets/Docs	Project-based Parameter/Target libraries	Enterprise PLM parameter/target mgmt & reuse	Integrated parameters, targets,... drive continuous compliance monitoring
Change management	Document-based change process	Isolated models included in change	Change impact analysis & suspision mgmt	Complete PLM configuration with models, parameters, history,...	Cross-project level reuse, starting point for next project
Content Management					
Requirements Analysis *Requirements engineering & mgmt*	Uncontrolled spreadsheets & docs	Managed requirements docs	Disconnected RM tools with exchange	Integrated requirements & traceability inside PLM	Continuous compliance thru connected, configured, cross-domain traceability & reuse
Behavior Model Management System, performance, et al simulation	Uncontrolled models on desktops	Version controlled models	SE artifacts linked into models	Integrated model & product configuration with simulation	Continuous, focused simulation & multi-domain , dash boards
Verification Management & Governance *Product Test/V&V*	Document-based test procedures	Managed test cases	SE artifacts linked to test	Devops-like V& simulation	focused testing, s, model swap out
Physcial Design Management *CAD, CAE,.. control/mgmt*	Unmanaged CAx models	PDM controlled CAx	SE artifacts linked into CAD	Cross-domain fine-grained PLM integration	Continuous physical design verification (Digital Twin)

You are here

Best Auto (best case)

Best Aero (best case)

Credit: INCOSE MBSE Initiative, 2024.

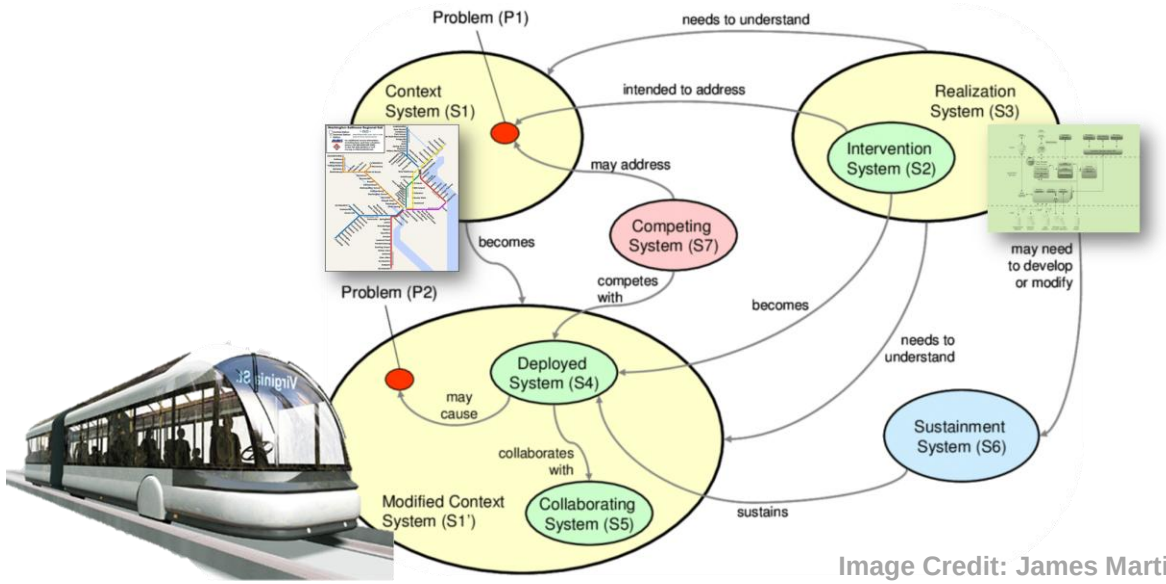
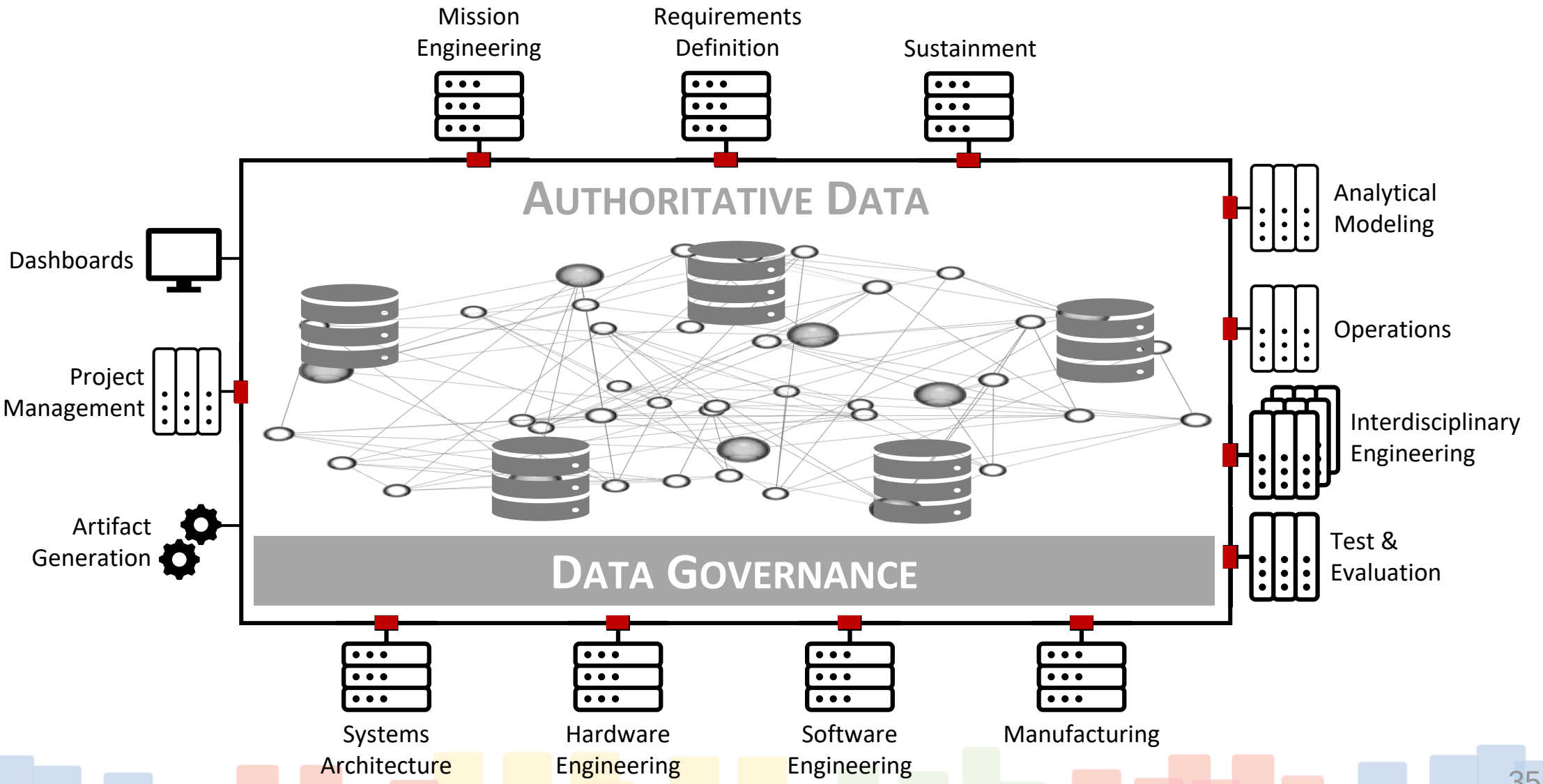


Image Credit: James Martin, Seven Samurai Framework

Deploying MBSE and DE

A system is a system is a system

Appreciating a Notional Environment for DE



Embracing Digitalization to Transform Engineering

More than Technology and Tooling

Digitization

Transitioning existing documents and processes as they are into a digital environment (for example, generating all artifacts for a preliminary design review from models)

Digitalization

Transforming existing approaches and artifacts to optimize for a connected digital environment (for example, shifting from milestone reviews to continuous customer and contractor reviews conducted in the DE environment).

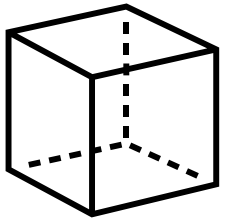
Digital Transformation
True transition from document-based acquisition to digital acquisition and engineering.

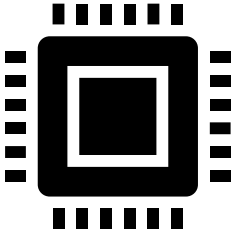
Hutchison et al. (2022)

Appreciating the Full Scope

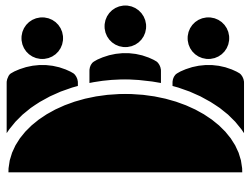
Dependencies and Interactions thru Life

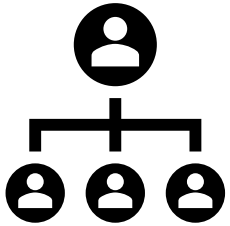
TECHNICAL





SOCIO

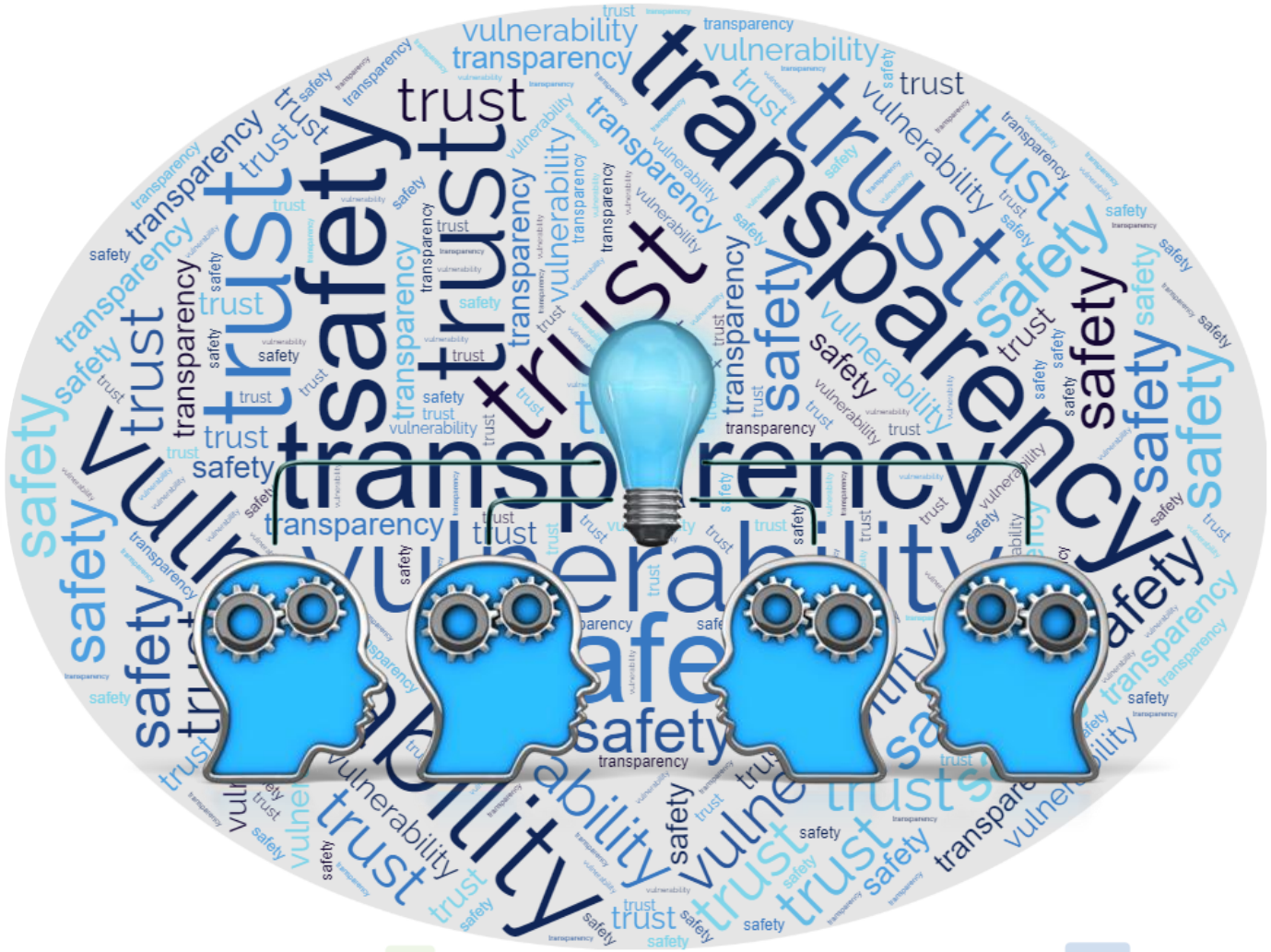




MANAGEMENT ● CURATION ● IP ● ACCESS ● SECURITY ● EFFECTIVITY

Embracing the Human Dimension

Unlocking Collective Intelligence



Identifying Traps

Classic Errors on the Journey to Model-Based and Digital

- Thinking it's a tool (or a technical) issue
- Implementing someone else's solution
- Ceding responsibility to a (tool) vendor
- Chasing standards
- Overlooking middle management
- Thinking sprint not marathon

Find Your Customer

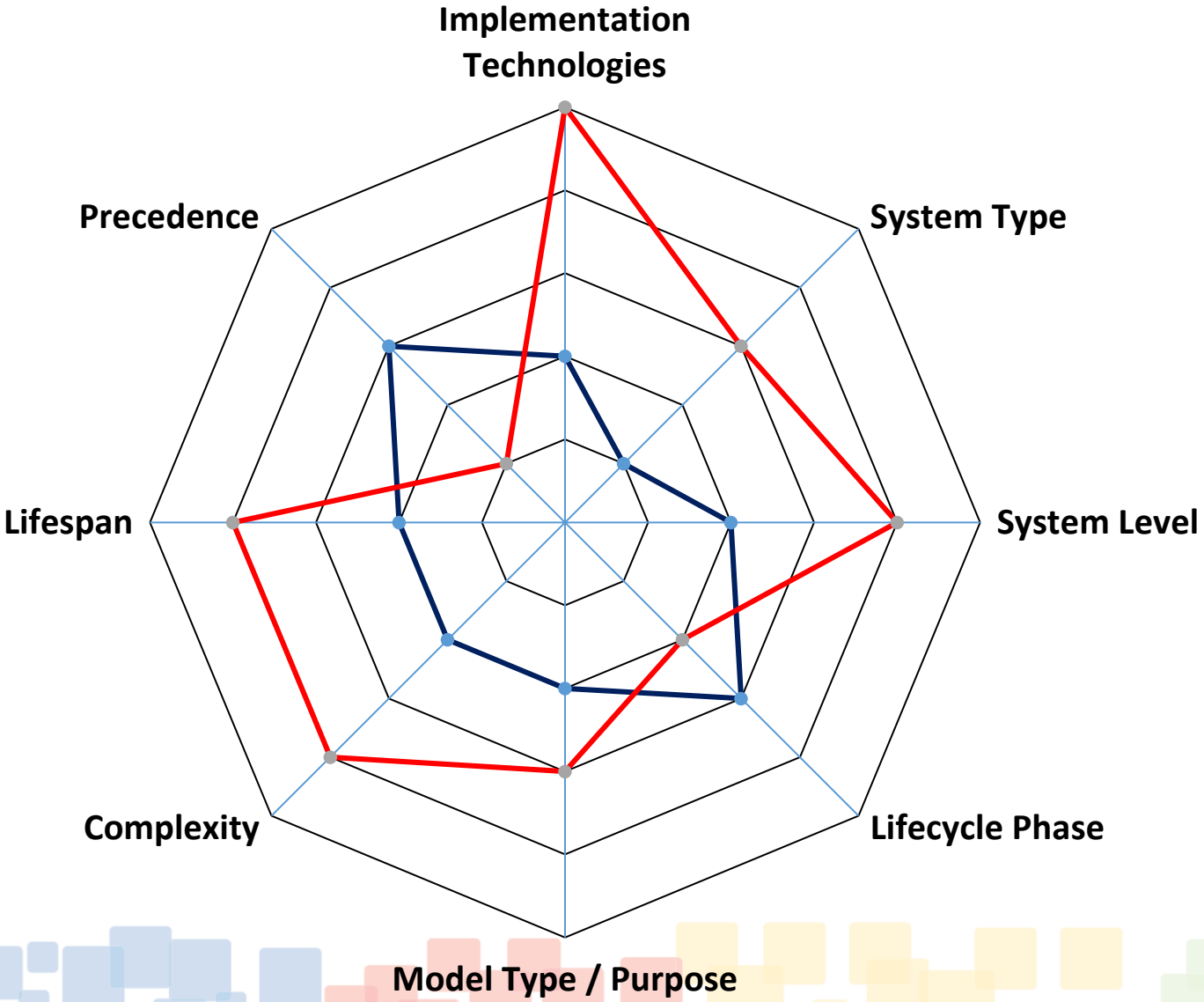
aka Your Champion

Find the people in your system most susceptible to having their situation improved. Focus on them, not technology.

Larry Leifer
Dancing with Ambiguity
INCOSE IS 2016

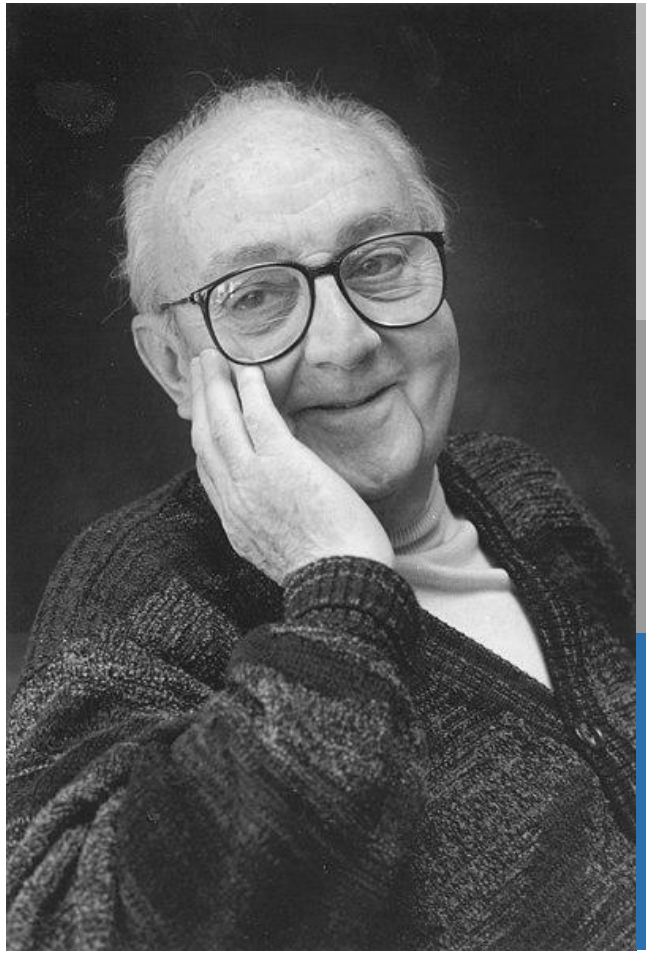
Begin with Your End in Mind

Good Systems Engineering is Always Fit-for-Purpose



Leverage the Thinking of George Box

Both Caution and Guidance



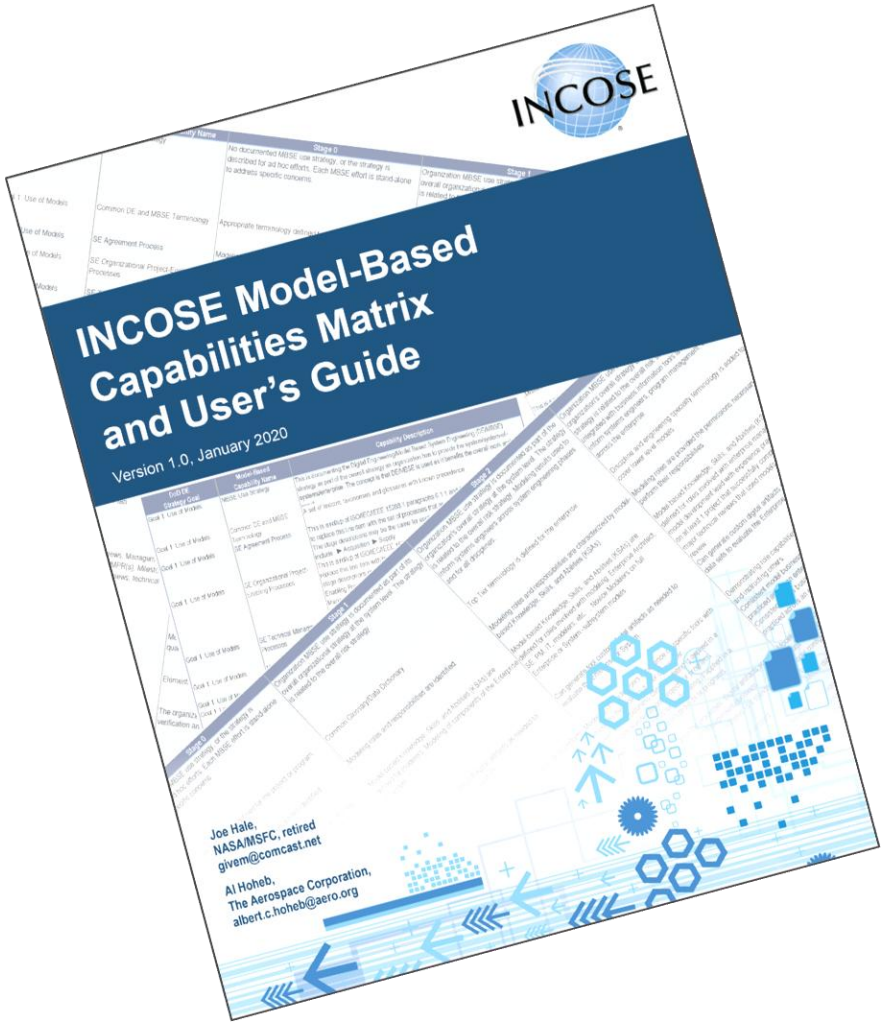
All models are wrong

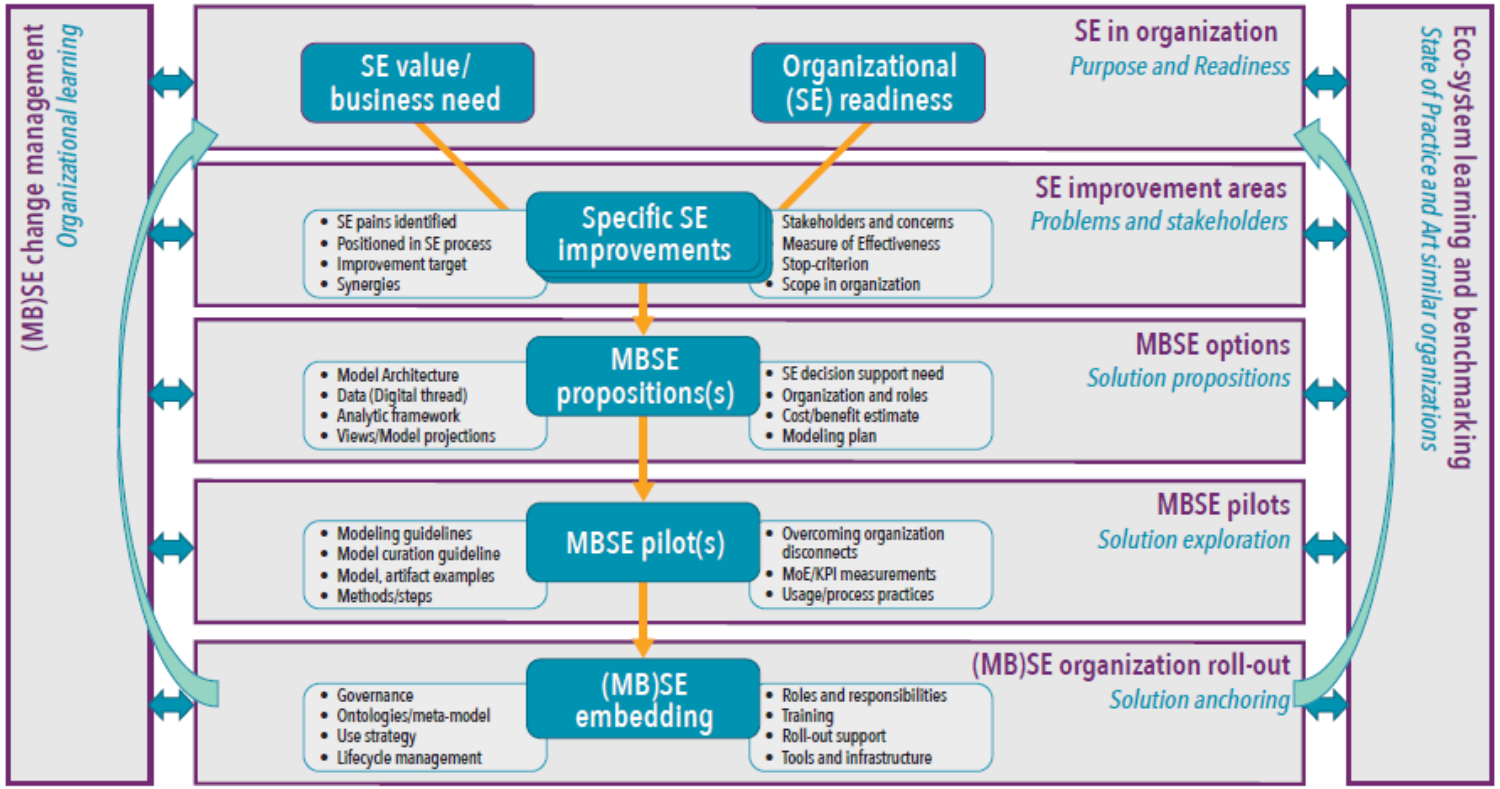
All models are wrong
but some are useful

The question is how wrong a model can be and still be useful

Assess Where You Stand Today

Undertaking a Journey Requires Both an As-Is and To-Be

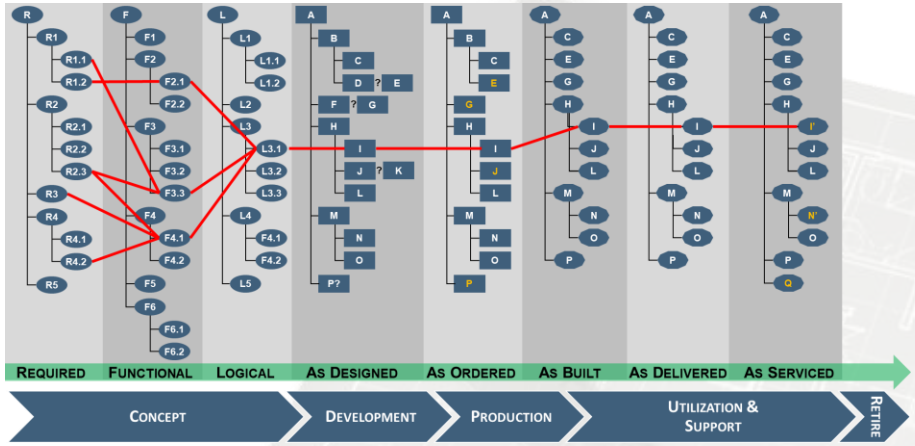




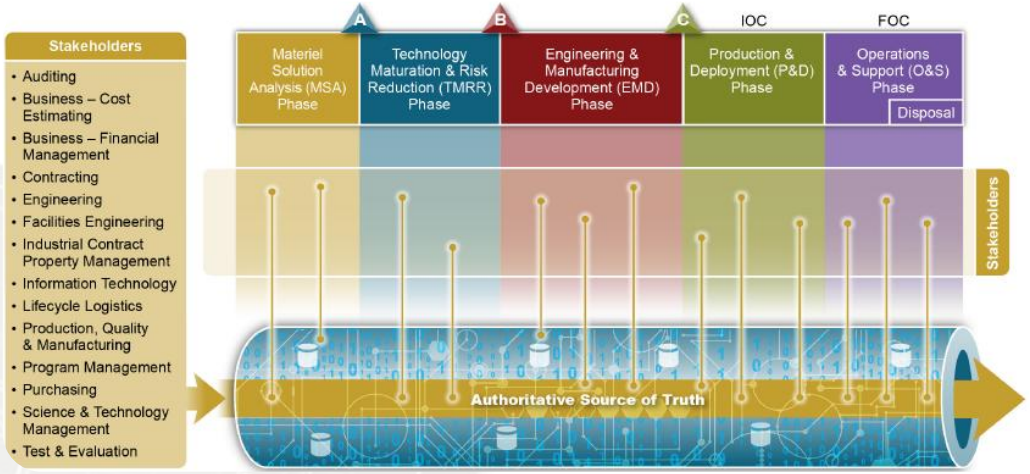
Credit: Creating Value with MBSE in the High-Tech Equipment Industry, Hendriks et al., INCOSE Insight Volume 25 Issue 4, December 2022.

Define Your Reach for Dx

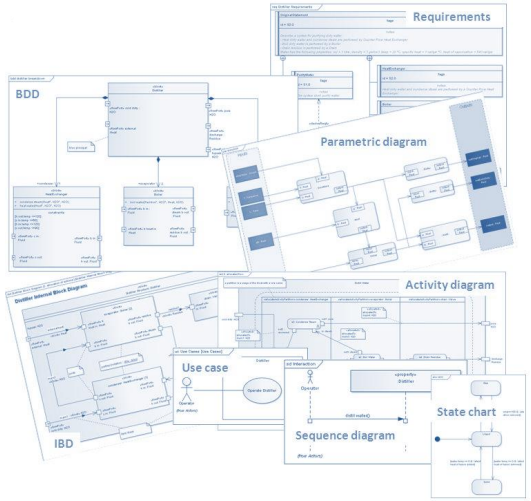
Where You Need to Be not Want to Be – SE, EoS, or Beyond?



Adapted from Aras Corporation, 2018



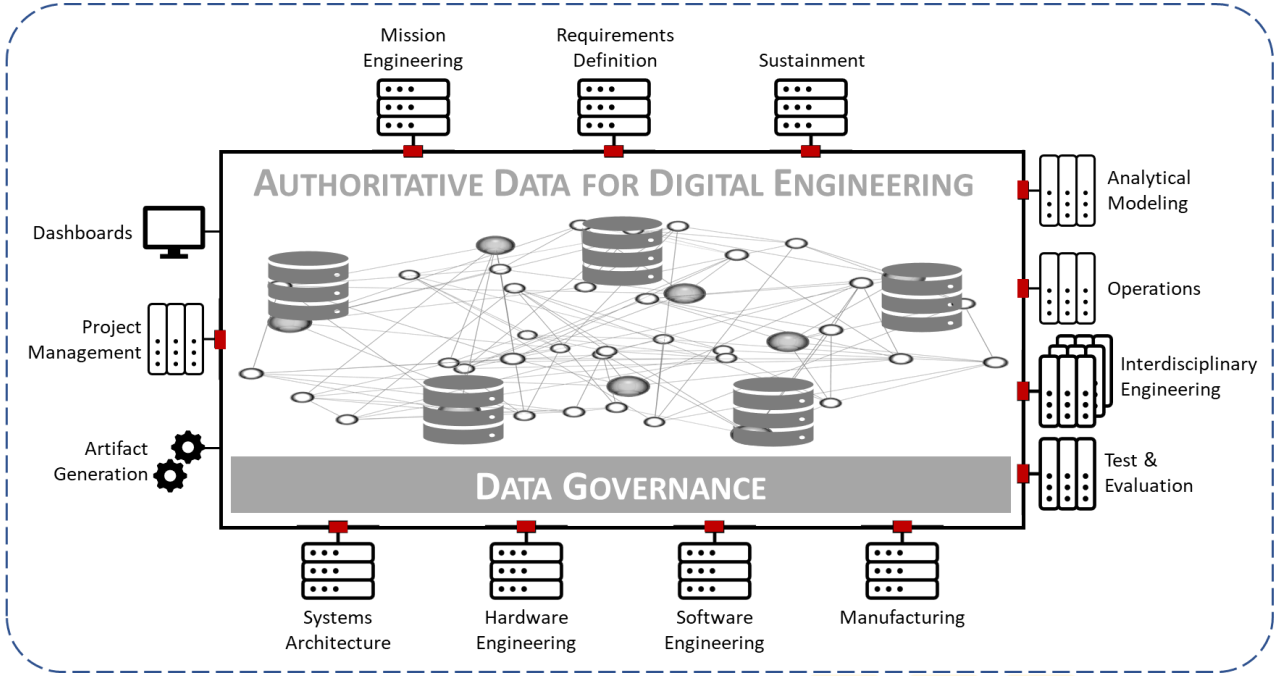
Credit: US Department of Defense, 2018

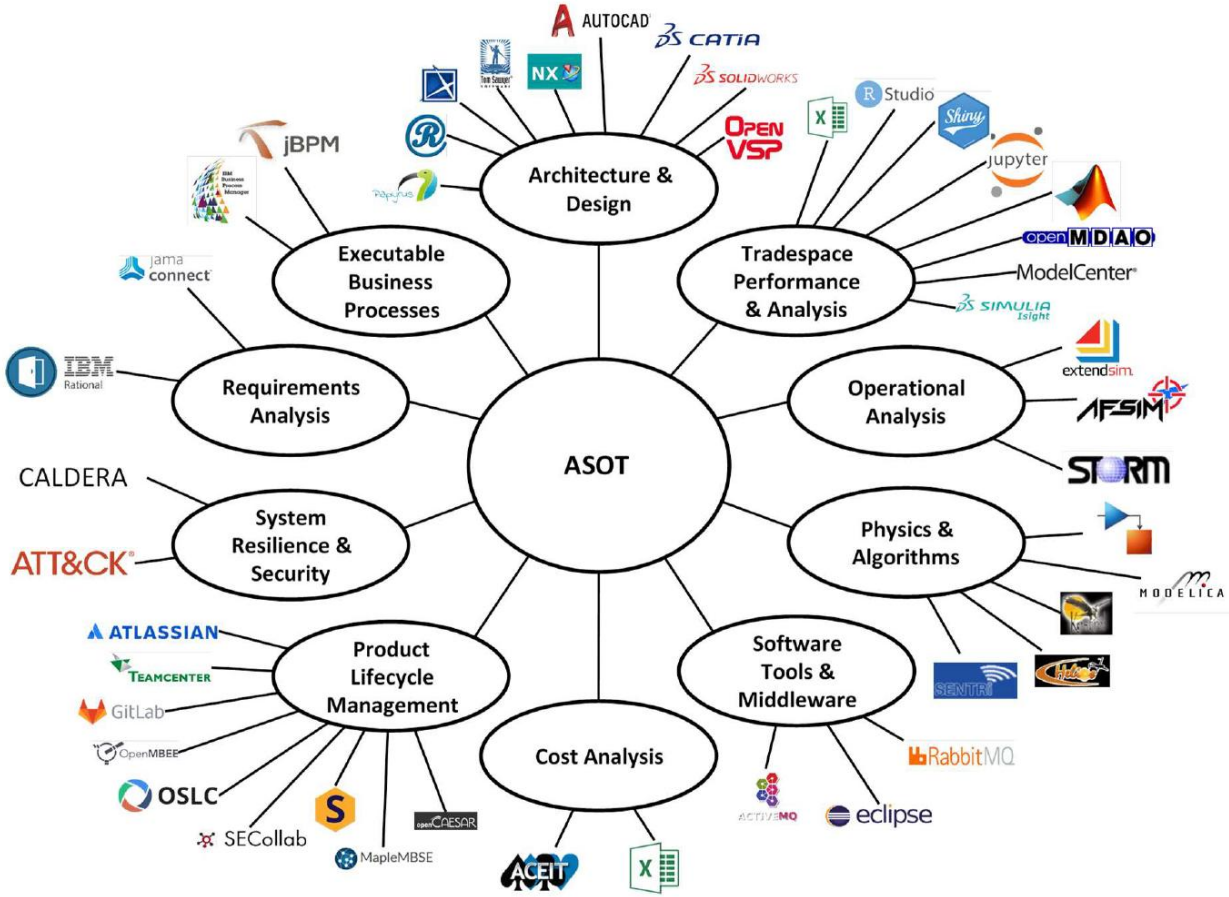


Credit: Sumit Awinash, Creative Commons 4.0

Appreciate and Honor Your Scope

Neither Benefit nor Difficulty Increase Linearly

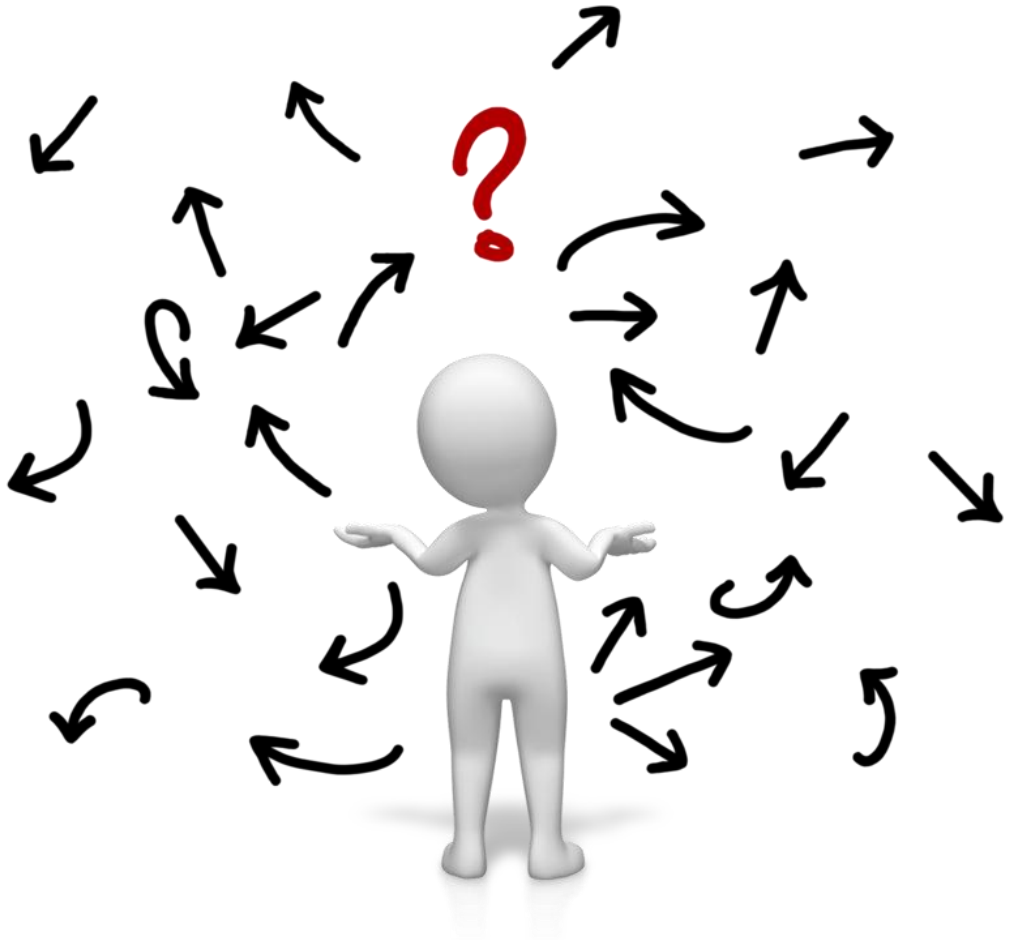




Credit: WRT-1051, Program Managers Guide to Digital and Agile Systems Engineering Process Transformation, August 2022

Elicit Requirements

Understanding Both Project and Journey



NEEDS

DESIRES

CONSTRAINTS

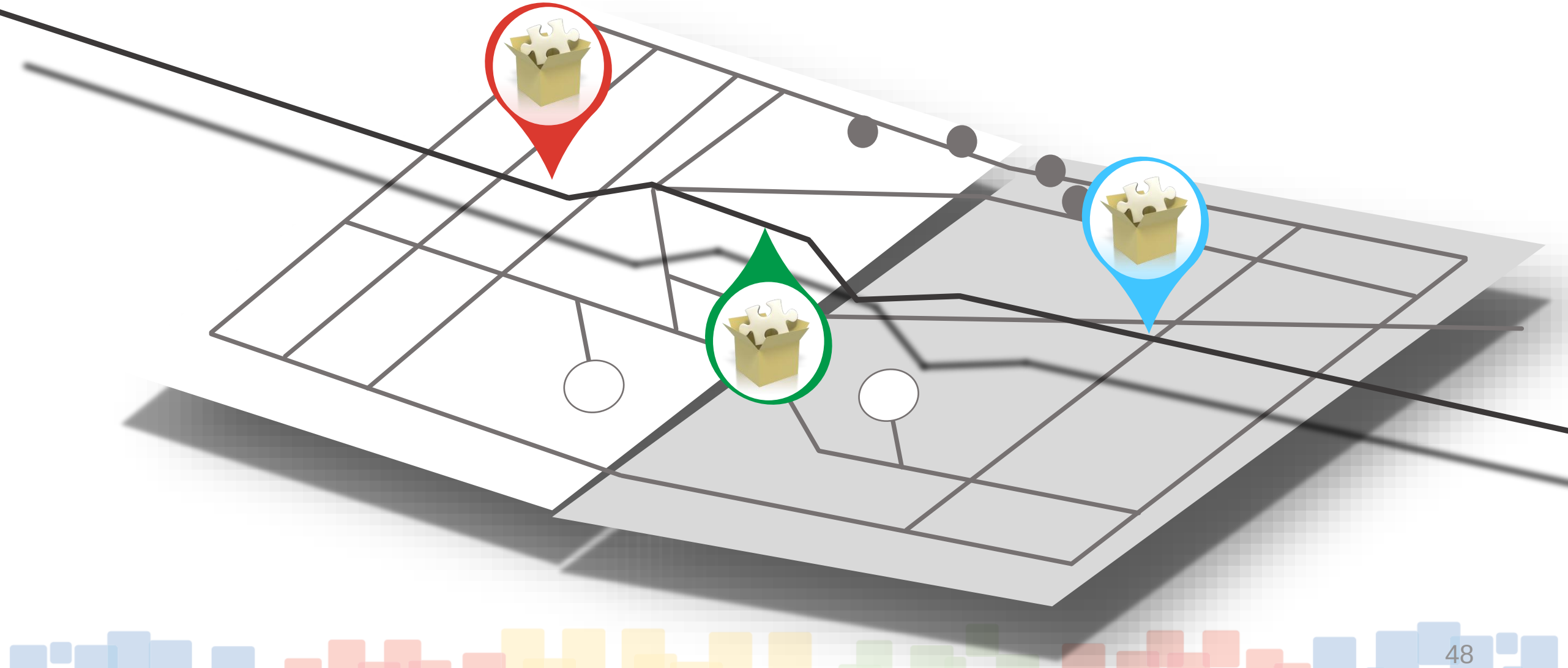
Apply the Power of the Black Box

Manage the Change Boundary

- ✓ Compartmentalize change
- ✓ Empower change agents
- ✓ Honor existing interfaces
- ✓ Honor interface formats
- ✓ Expand intentionally

Engineer the Outcomes and the Change

Plot and Adapt the Journey Map



Driving the Change – Up, In, and Out

Transformation Must Live Outside the Silos

- Recognize it's not "if" but "when" and "how well"
- Be informed – about the topic, customer, team, vision, and journey
- Move beyond positions to interests
- Align to and guard the why
- Sell through attunement, buoyancy, clarity – *To Sell is Human* (Pink)
  - Sell technologies only to technologists
  - Move the conversation from cost to value (but beware the Shanri-La of ROI)
  - Under-promise and over-deliver (and don't underestimate the costs of transformation)
- Champion systemic considerations and systemic change
  - Through-life considerations and concerns
  - Thinking and engineering

***Prioritize your letters* – E then S before D and M then lastly B**

Continuing the Conversation

David Long, ESEP
Director for Strategic Integration
Past President (2014/2015)
Fellow

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