Digital Engineering Research

Keynote: Model Based Space Systems and Software Engineering - MBSE2020

Dinesh Verma, Ph.D.
Professor of Systems Engineering; Executive Director, SERC

This material is based upon work supported, in whole or in part, by the U.S. Department of Defense through the Systems Engineering Research Center (SERC) under Contract H98230-08-D-0171. The SERC is a federally funded University Affiliated Research Center (UARC) managed by **Stevens Institute of Technology** consisting of a collaborative network of over 20 universities. More information is available at www.SERCuarc.org

Who am I?

- **Technical Director** and Senior Technical Staff Member (STSM), Lockheed Martin Undersea Systems; 1997 to 2001
- **Professor** of Systems Engineering, Stevens Institute of Technology; September 2001 to Present;
- **Founding Dean**, School of Systems and Enterprises, Stevens Institute of Technology; March 2007 to December 2016
- **Executive Director** of the SERC; September 2008 to Present;

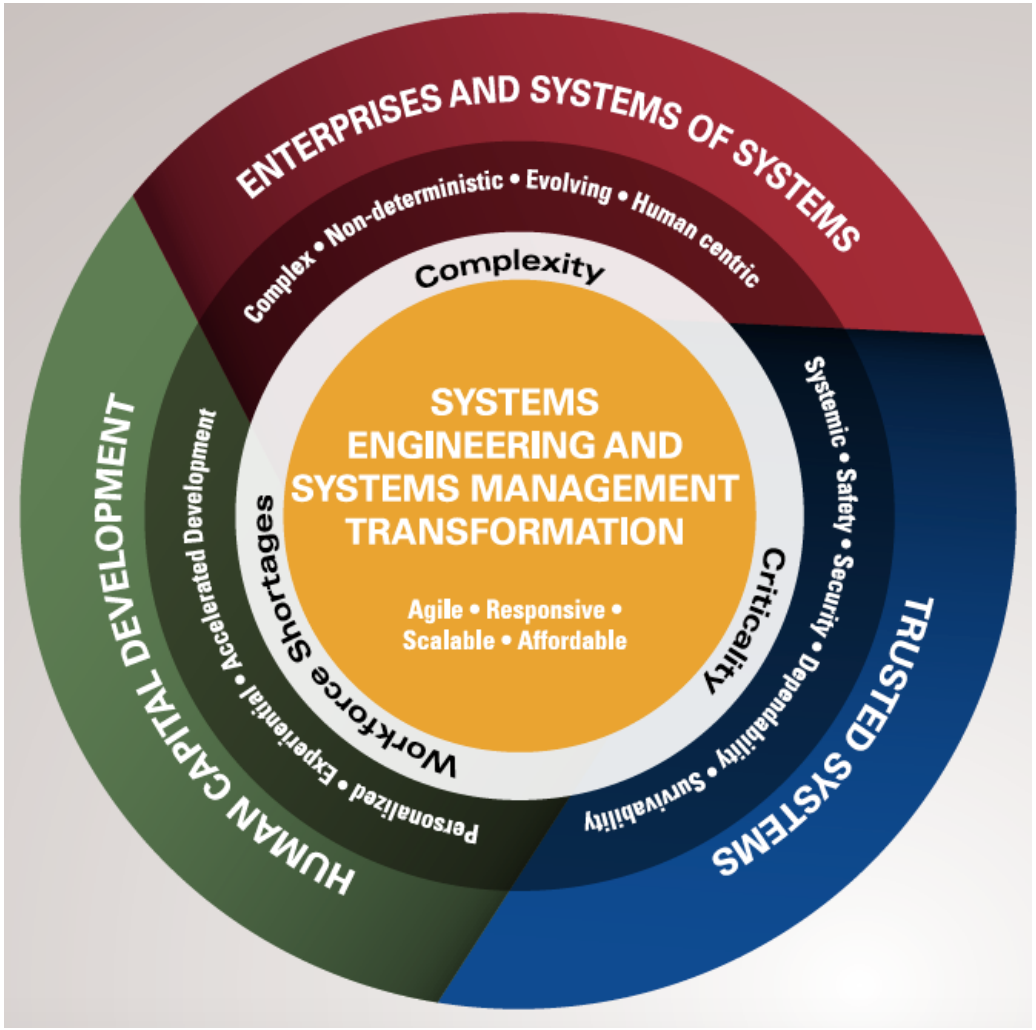
SERC: A Brief History

- In 2008, the DoD released a full and open competitive RFP for a University Affiliated Research Center (UARC) on systems engineering research
- Stevens Institute of Technology led a team that brought together much of the best systems engineering research talent in the nation to form a stable and enduring collaboration to the benefit of the DoD
- Stevens was awarded the SERC in September 2008
  - Vested through a 5-year, renewable, task order based IDIQ contract with DoD
  - Contract renewed in with WHS in September 2018 for the next five years (POP 2018-2023)
  - A second 5 year contract with ACC at Picatinny Arsenal was awarded in Summer of 2018 – this allows outreach of the SERC to the rest of the Federal Agencies
- SERC has been awarded almost $100M in research tasks (from 2008–2020)
- SERC is unique among UARCs
  - Only UARC funded at the DoD level – USD(R&E)
  - Only UARC consisting of a collaborative network of universities
  - Only UARC created to address the entire domain of systems engineering – education, research, and practice

SYSTEMS ENGINEERING RESEARCH CENTER

The Systems Research and Impact Network

SERC Research Thematic Areas



Enterprises and SoS

- *Comprehensive Enterprise/ SoS Modeling and Analysis*
- *Mission Engineering*
- *Digital Enterprise Transformation*

Trusted Systems

- *Systemic Security*
- *Systemic Assurance*

Human Capital Development

- *Evolving Body of Knowledge*
- *Experience Acceleration*
- *SE and Technical Leadership Education*
- *Emerging/Critical Human Capital*

SE & Systems Mgmt Transformation

- *Systems Engineering for Velocity and Agility*
- *Digital Engineering*
- *SE Methods for AI and Autonomous Systems*

SERC Research Council Members

Enterprise Systems and Systems of Systems

- ***Dan DeLaurentis, Purdue***
- *Bill Rouse, Georgetown (NAE)*


Systems Engineering and Systems Management Transformation

- *Barry Boehm, USC (NAE) – RC Chair*
- *Mark Blackburn, Stevens*
- *Paul Collopy, UAH*



Trusted Systems

- *Peter Beling, UVA*
- *John Colombi, AFIT*
- *Laura Freeman, Virginia Tech*
- *Val Sitterle, GA Tech*




Human Capital Development

- *Cliff Whitcomb, NPS*

SERC Research Areas and Missions

Mission Engineering

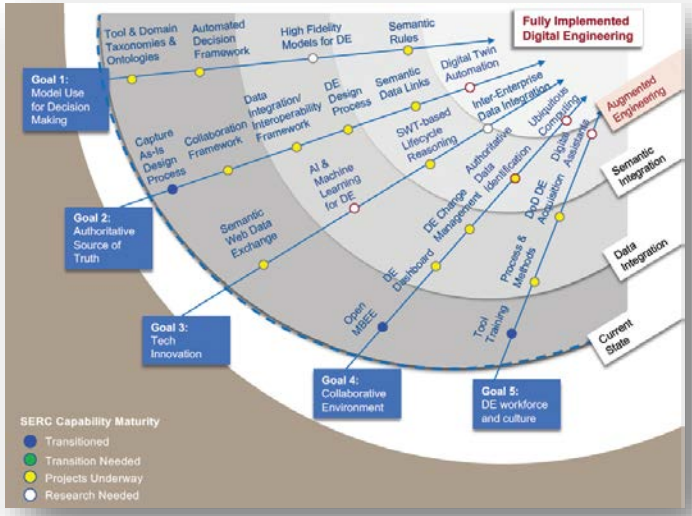
	TRUSTED SYSTEMS	ENTERPRISES AND SYSTEMS OF SYSTEMS	SYSTEMS ENGINEERING AND MANAGEMENT TRANSFORMATION	HUMAN CAPITAL DEVELOPMENT
V	**VELOCITY** Developing and sustaining capabilities that support emergent and evolving mission objectives (deter and defeat emergent and evolving adversarial threats and exploit opportunities, affordably and with increased efficiency)			
S	**SECURITY** Designing and sustaining the demonstrable ability to safeguard critical technologies and mission capabilities in the face of dynamic (cyber) adversaries			
A	**AI & AUTONOMY** Developing and supporting system engineering MPTs to understand, exploit and accelerate the use of AI and autonomy in critical capabilities			

SERC Technical Plan Roadmaps

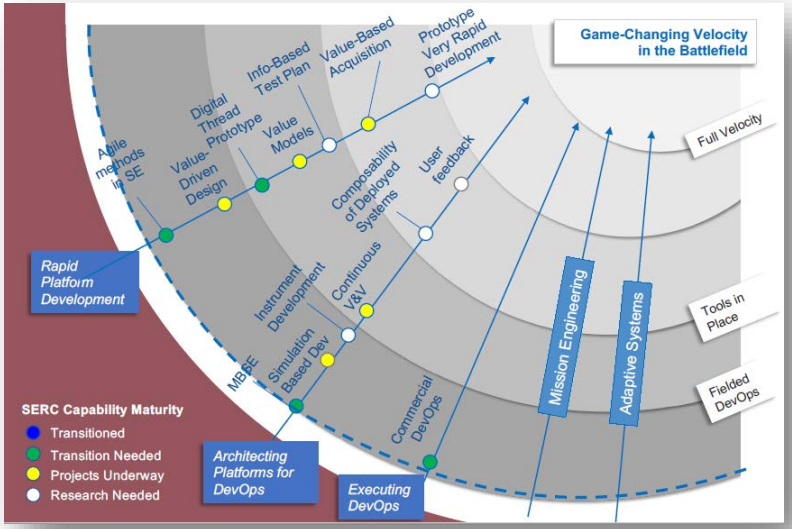
Digital Engineering

SERC Research Roadmaps

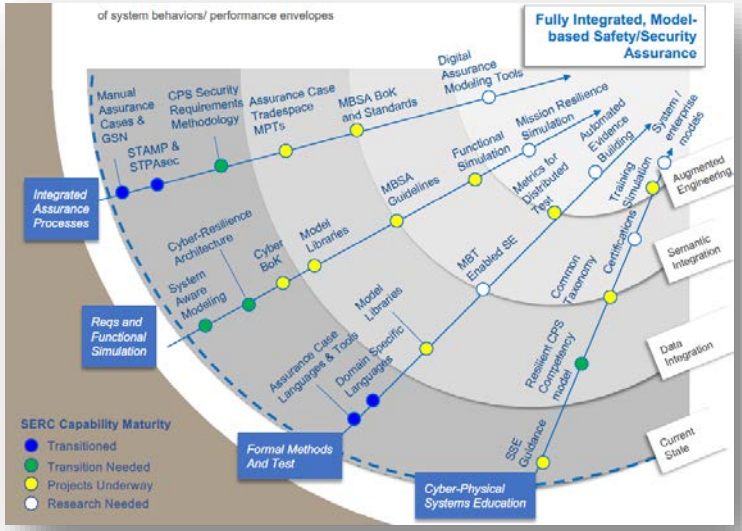
Digital Engineering



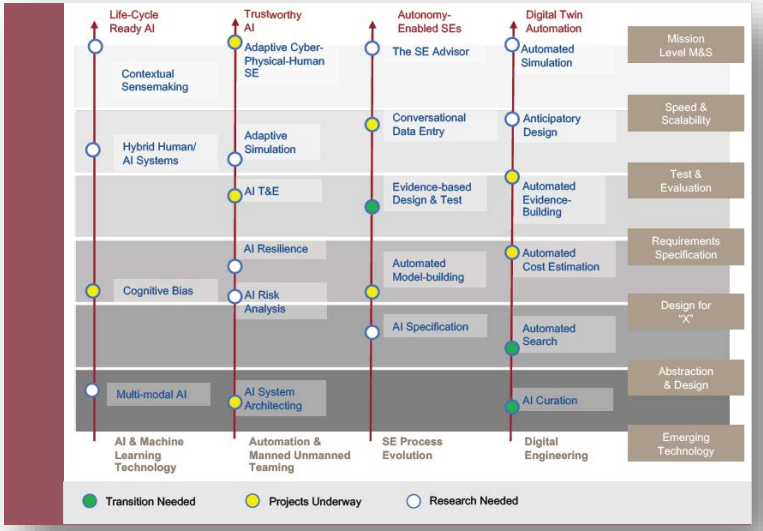
Velocity



Security

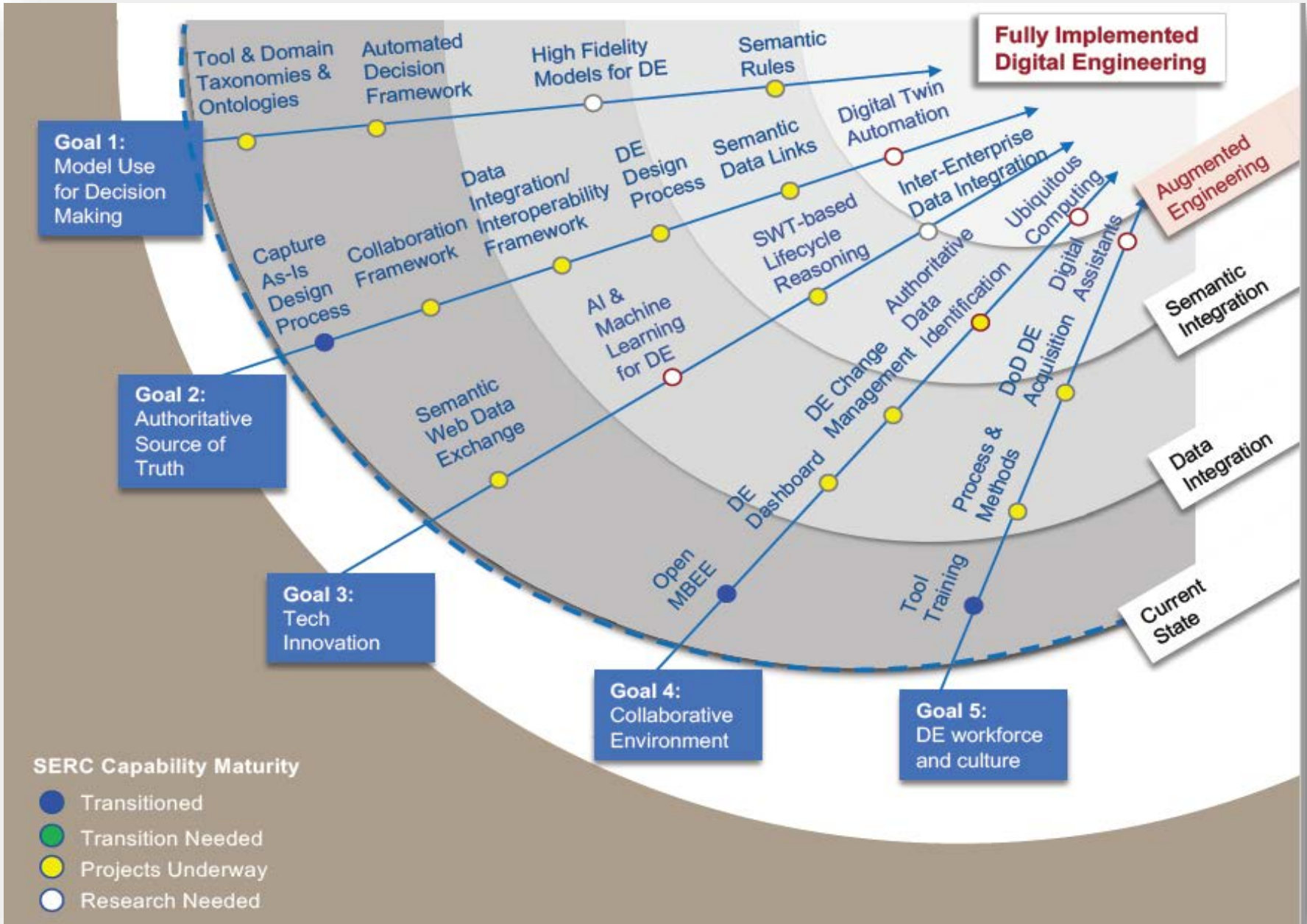


AI & Autonomy



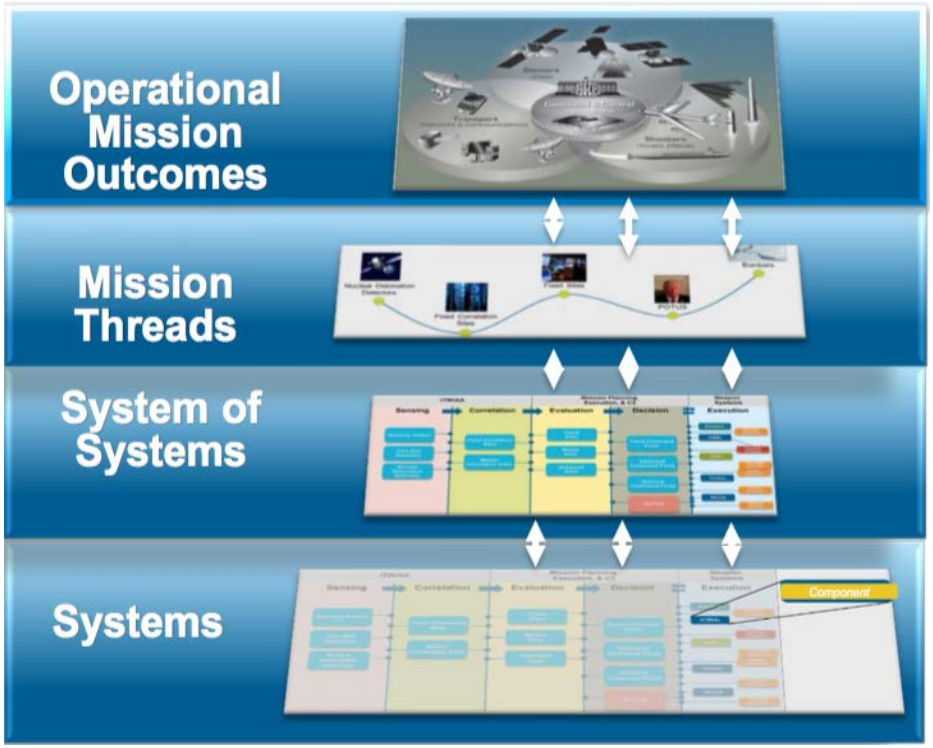
SYSTEMS ENGINEERING RESEARCH CENTER

Digital Engineering Roadmap – the Enabler



DoD DE Strategy – Discussion Framework

- DE/MBSE helps refactor and strengthen implementation of Systems Engineering principles (Goal 3)
  - Represent Structure, Behavior, Interfaces, Requirements and related interactions
  - Can characterize different levels of abstraction – Mission, System, Subsystem where different types of methods are needed
  - Can generate "documents/specifications" based on stakeholder-relevant views
- DE requires a formalized system/design representation that links information in an Authoritative Source of Truth (Goal 2)
- Need computation and methodological infrastructure for access and visualize on need-to-know basis (Goal 4)
- Semantically linked system/design information to enable tradespace analyses and decision making (Goal 1)
- USE CASEs to present research progress



Extending the DoD Digital Engineering Strategy to Missions, Systems of Systems, and Portfolios
P. Zimmerman, T. Gilbert, J. Dahmann
22nd Annual NDIA Systems and Mission Engineering Conference
Tampa, FL| 23 October 2019

Digital Engineering Transformation

- Will change the way **Engineering** is done
- Will change the way DoD **Acquisition** is done

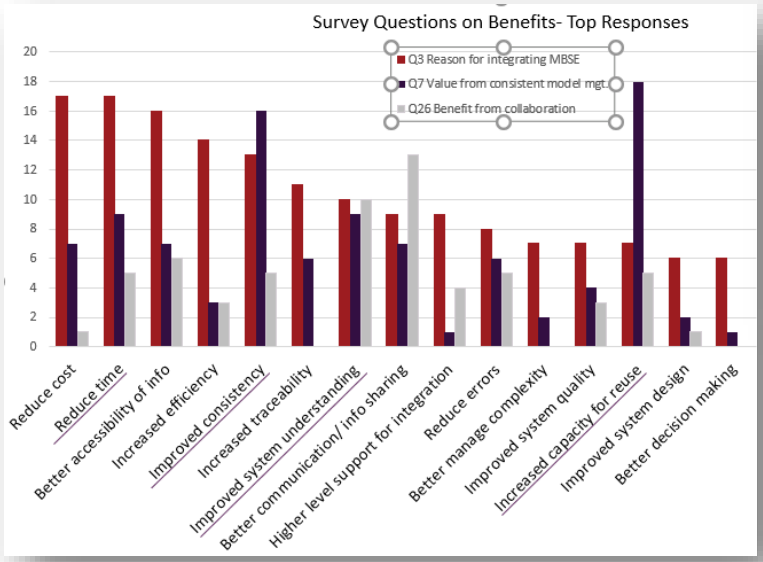
Systems engineering will lead the effort to **drive out unnecessary complexity** through well-founded architecting and deeper system understanding

A **virtual engineering environment** will incorporate modeling, simulation, and visualization to support all aspects of systems engineering by enabling improved prediction and analysis of complex emergent behaviors.

Composable design methods in a virtual environment **support rapid, agile and evolvable designs of families of products**. By combining formal models from a library of component, reference architecture, and other context models, different system alternatives can be quickly compared and probabilistically evaluated.

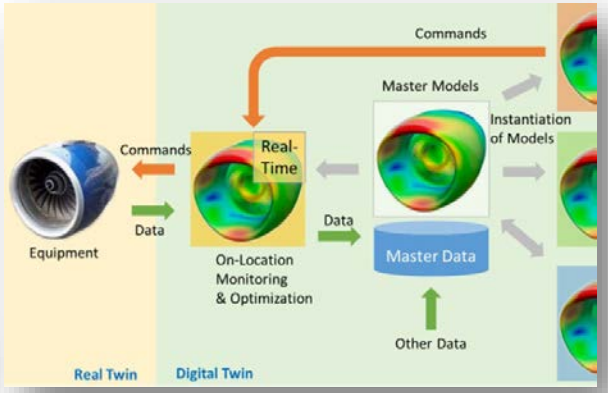
INCOSE SE Vision 2025/

DoD Digital Eng. Strategy

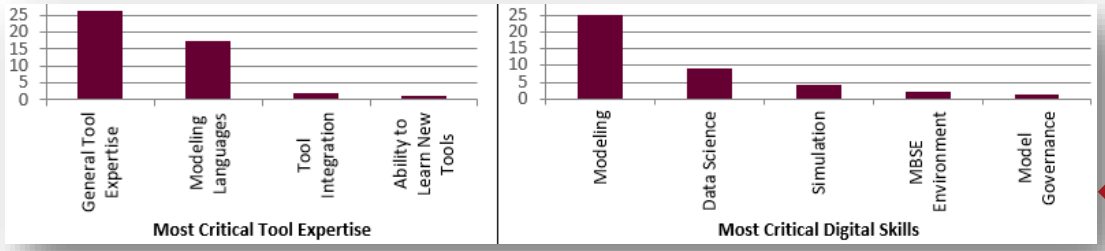


- Will change the way we view **quality** and **agility**

- Will change the way systems get **deployed**



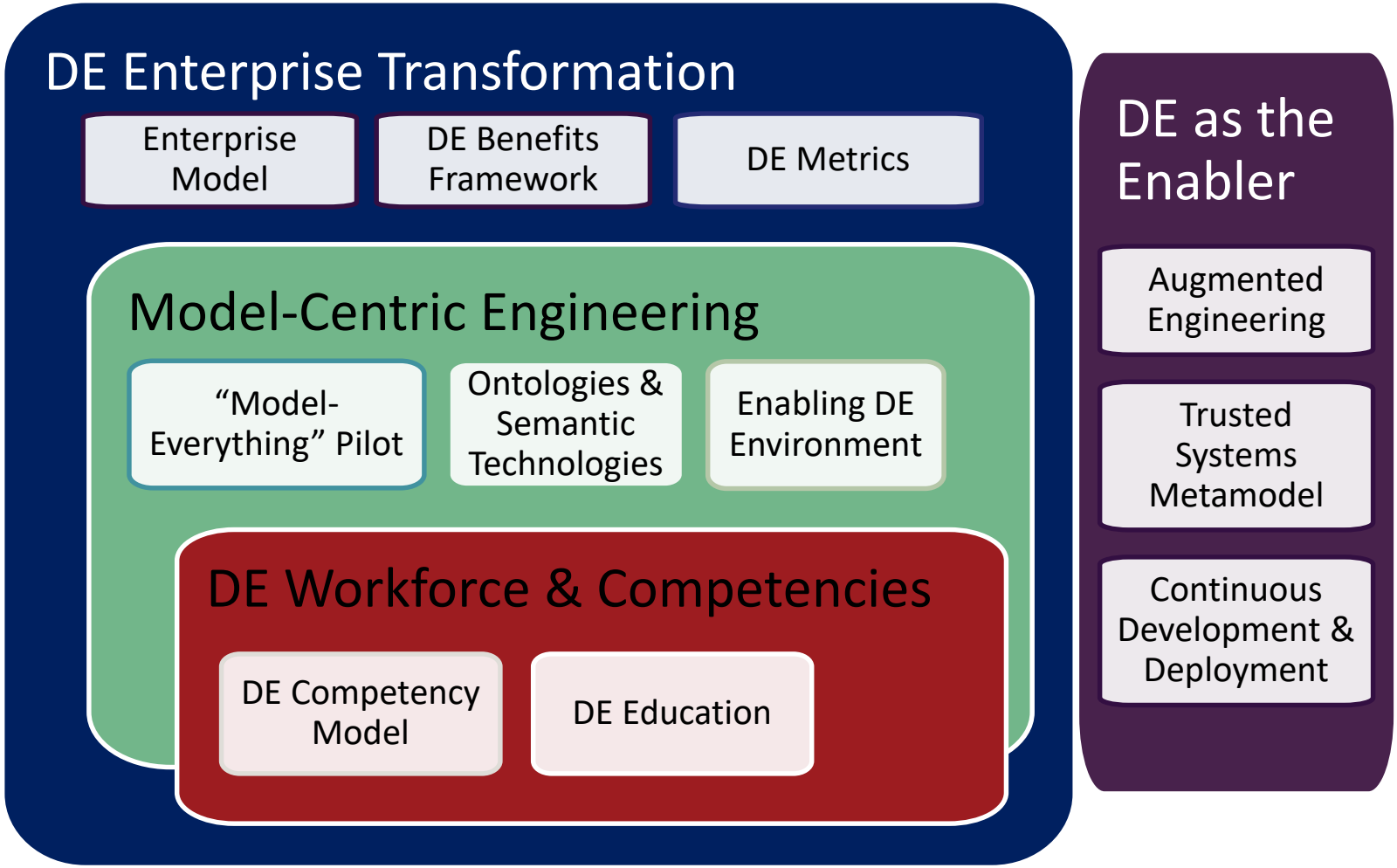
Report: Industrial Internet Consortium: Digital Twins for Industrial Applications.



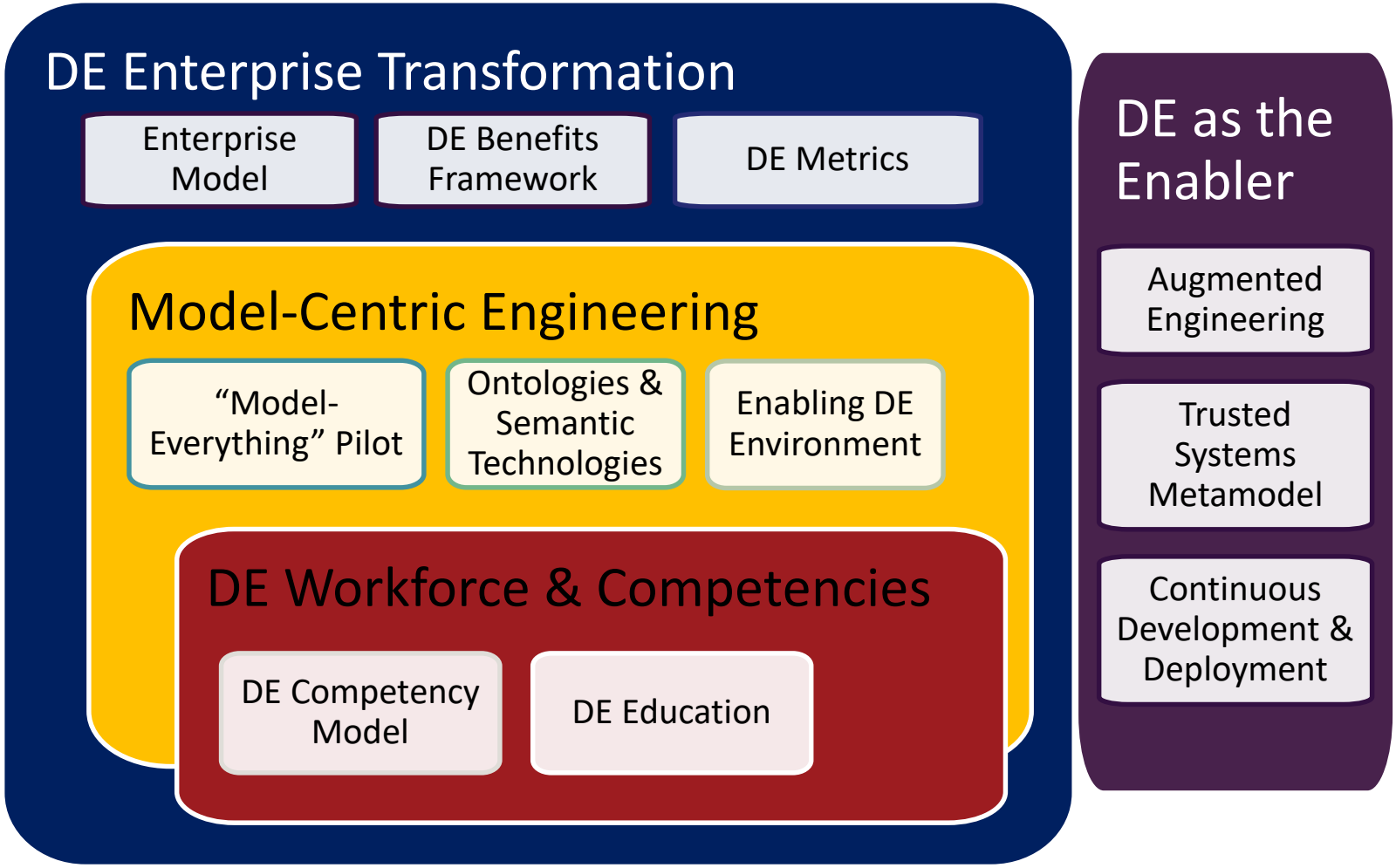
Data from SERC-SR-2020-001, Benchmarking the Benefits and Current Maturity of MBSE

- Will change our **workforce**

SERC Digital Engineering Research



SERC Digital Engineering Research



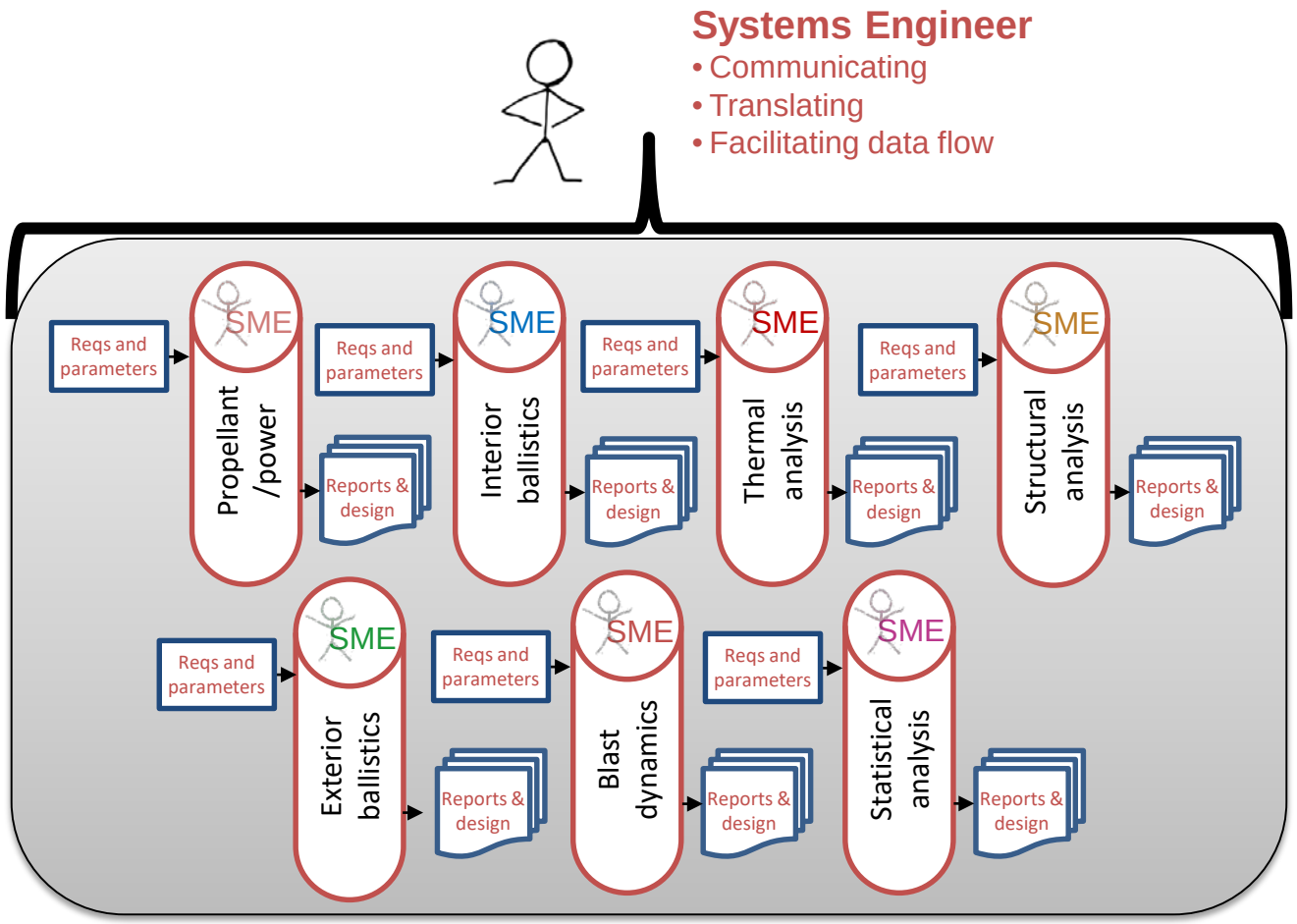
Use Cases to Convey how Digital Engineering will Transform Systems Engineering, from the Perspective of a Chief Engineer

Use Case #1
Round trip from Mission Level Analysis to Component Level Analysis and back

Use Case #2
Digital Signoffs in Authoritative Source of Truth using a Collaborative Environment

Use Case #3
From Configuration Management to
Model Management

Example: As-Is Engineering – Document Intensive with Disciplinary Stovepipes



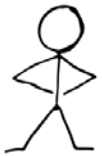
Example: Cross Domain Relationships Needed for System Trades, Analysis and Design

- Scenario Refueling UAV
- Valve – Cross-domain **Object**
- Mechanical **Domain**
  - Valve connects to Pipe
- Electrical **Domain**
  - Switch opens/closes Value
  - Maybe software

- Operator **Domain**
  - Pilot remotely sends message to control value
- Communication **Domain**
  - Message sent through network
- Fire control **Domain**
  - Independent detection to shut off valve
- Safety **Domain**

Opportunities to Refactor and Improve the As-Is Analysis & Design Process

- **Lots of software tools** – used for different analyses, by different communities
- **Lack of tool integration and interoperability** – different syntaxes, variable names & terminologies, and units, plus the need for SME input
- **Lack of consistency in modeling process and methods** – if an update is made one place, it's a challenge to ensure that it propagates into other models
- **Time consuming and labor-intensive to iterate** – making a small change somewhere requires substantial additional work everywhere
- **Difficulty in using models for strategic decisions** – non-SMEs have difficulty running and interpreting results to fully understand trends and tradeoffs

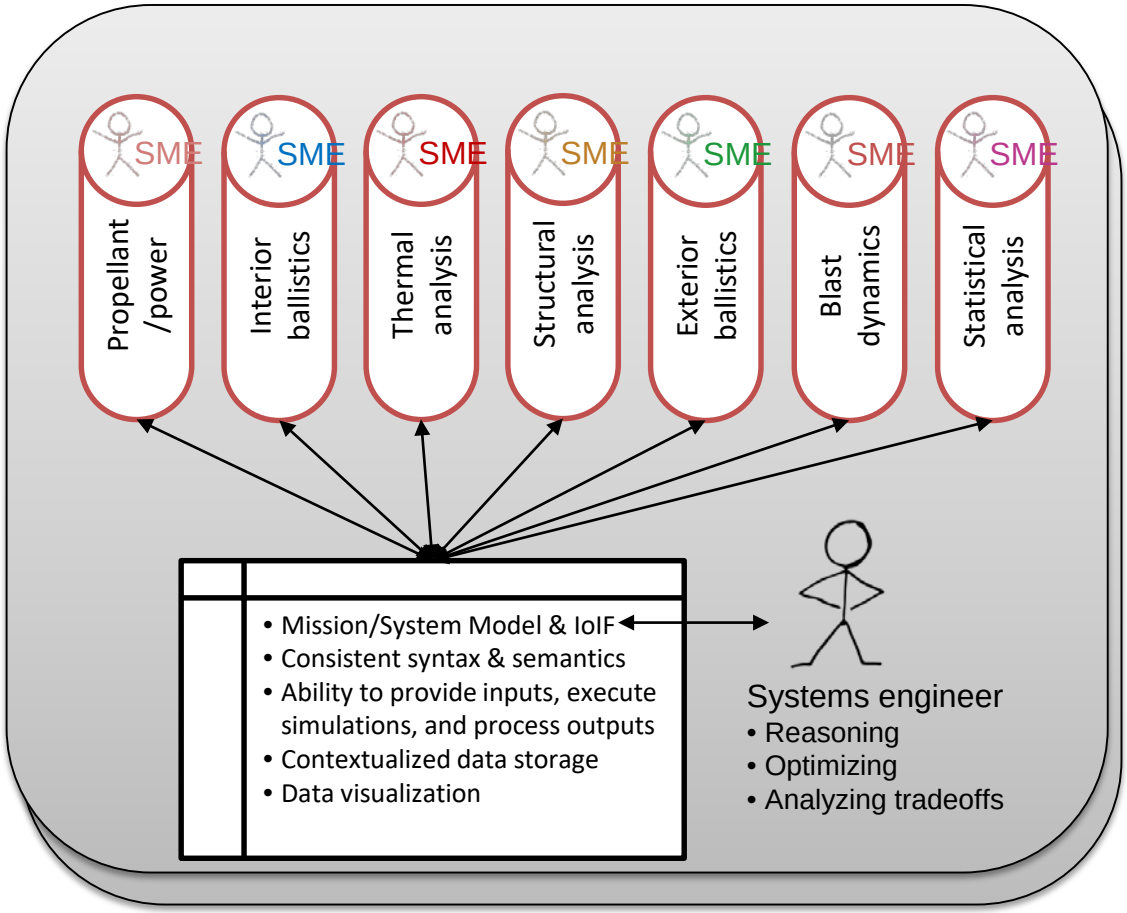


Systems Engineer

Systems Engineers are expected to facilitate and overcome all these issues in the current design process.

17

Aspirational High-level Research Vision, facilitated by Digital Engineering



Strategic/mission-level decision-maker

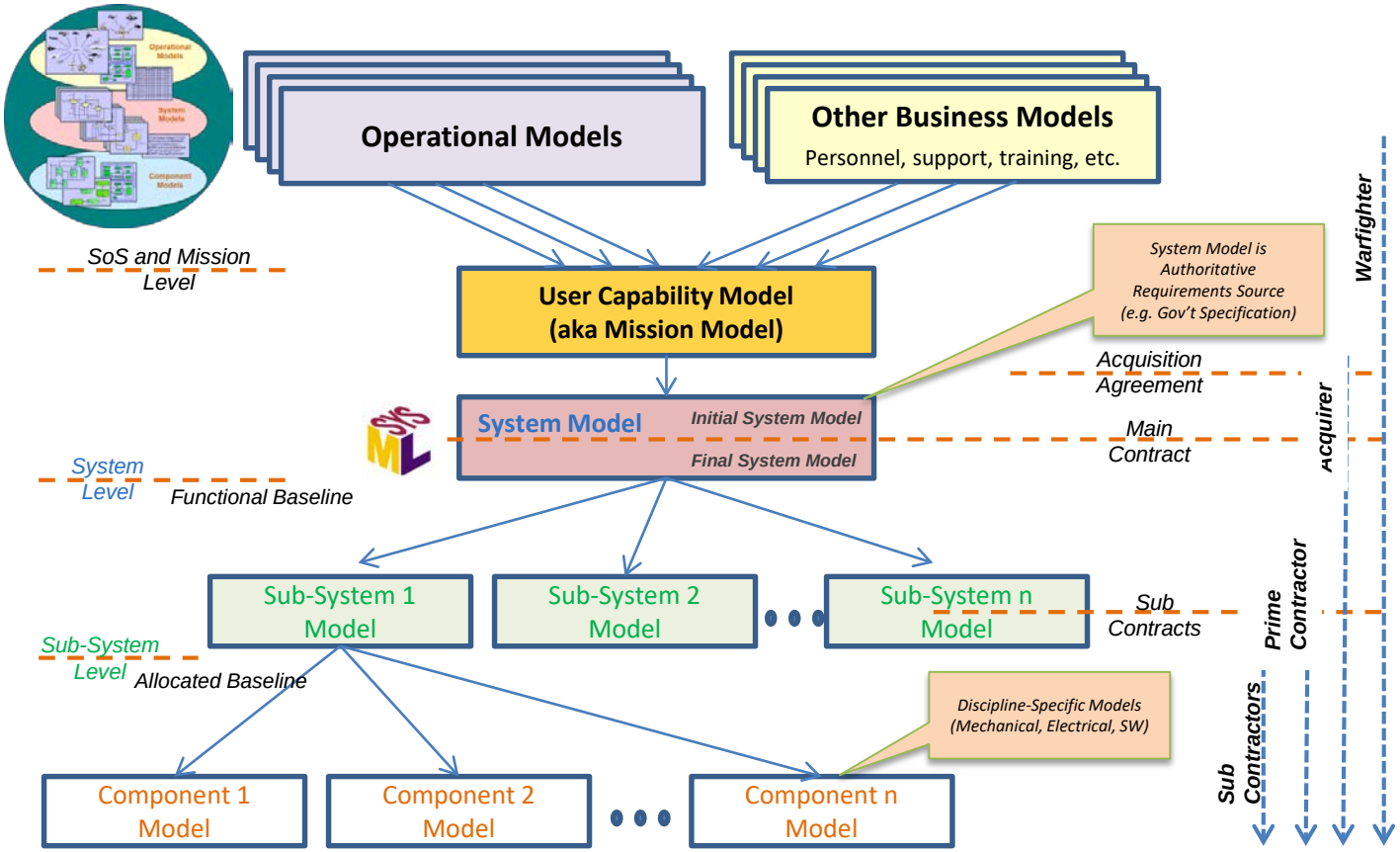
- Setting requirements & objectives
- Exploring tradeoffs
- Adjusting requirements & objectives based on capability information

Enabling Concepts – Not an Exhaustive List

- **Descriptive models**
  - They have a formal syntax and semantics reflected with a graphical language
  - They represent Structure, Behavior, Interfaces, Requirements and related Interactions
  - They can characterize different levels of abstraction – Mission, System, Subsystem where different types of methods usually apply
  - They can generate "documents/specifications" based on stakeholder-relevant views
- **Modeling Methods and Methodology**
- **Ontologies and Semantic Technologies enabler for interoperable AST**
  - Provides a means to link data across all domain (like the Internet)
  - Provides semantics to support Knowledge Representation, which is an enabler for AI
  - **Interoperability and Integration Framework (IOIF)**
- **Enabling Digital Engineering Environment**
- **Multi-Disciplinary Design Analysis and Optimization**
  - Enabling Technologies for Tradespace Analysis
- **Modeling Pattern (s)** characterizes "integrated" interplay of three related aspects
  - Target system (Sub-System 1)
  - "Designing" system – processes, methods, models, tools and computing infrastructure (Sub-System 2)
    - Model of the Target system is actually part of System 2
  - "Evolving" system – encapsulates both Target and "Designing" system (System 3)
  - There are continuous dynamics that influence all three systems

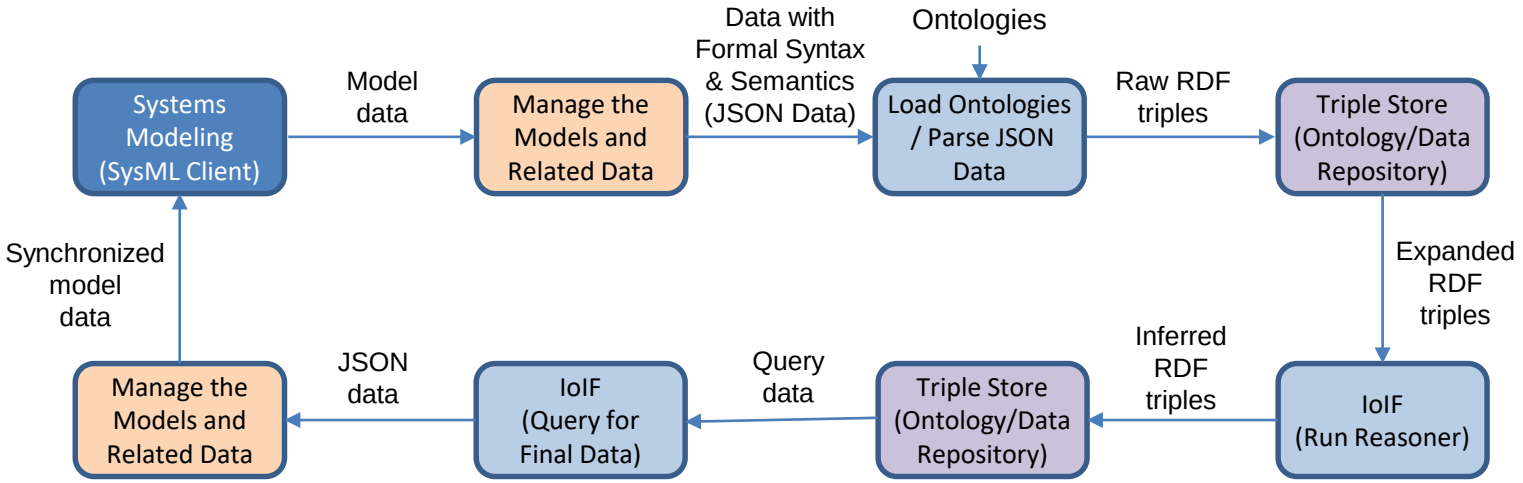
SYSTEMS ENGINEERING
Research Center

Modelling Levels where Appropriate Model Methods are Needed for Different Concerns



Component Data Flow for Full "Round Trip"

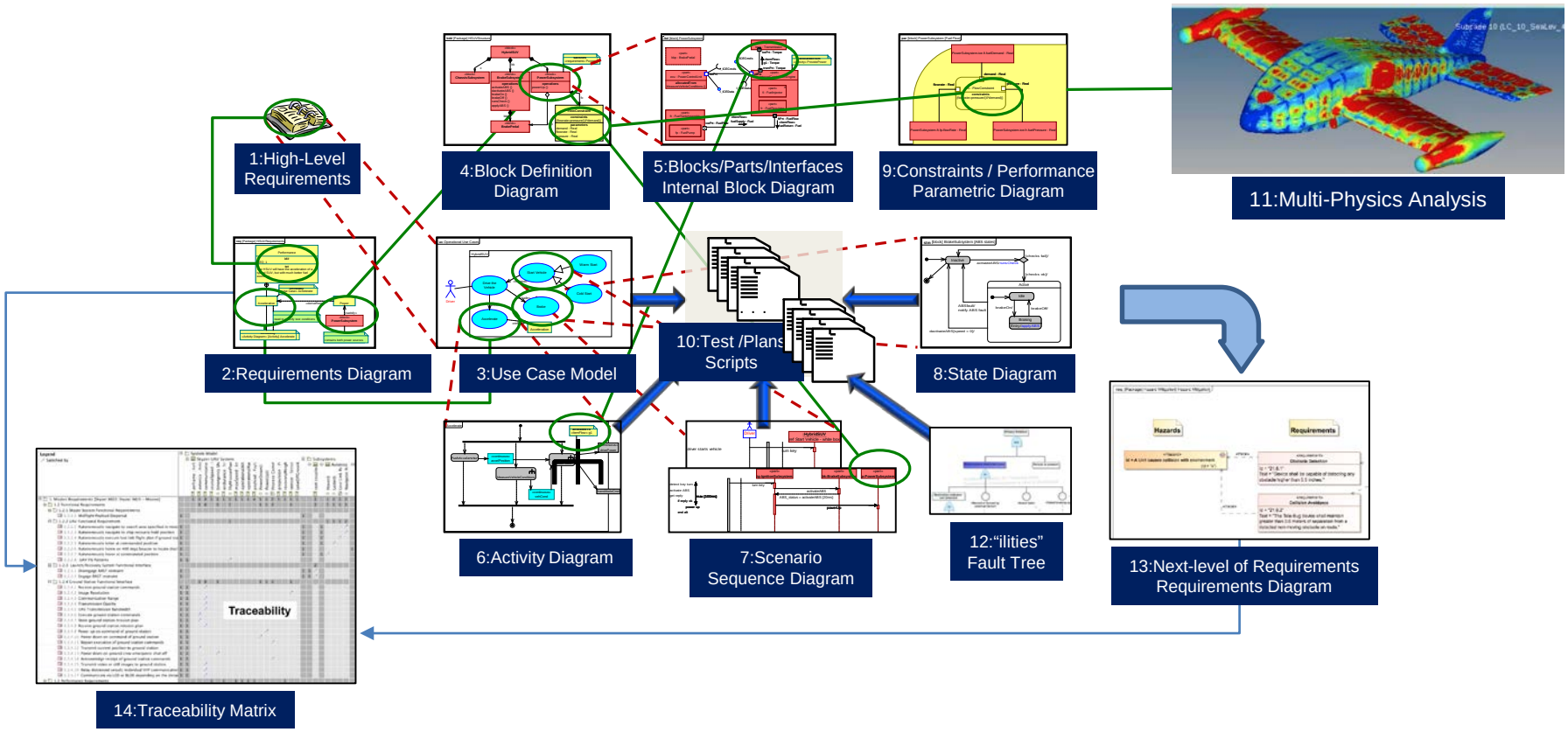
- Full round trip from System Modeler, through MMS, IoIF, and then back to Systems Modeler, with visualization in View Editor



RDF: Resource Description Framework is W3C standard for data interchange on the Web
JSON: Java Script Object Notation is a human/tool readable lightweight data-interchange format

SYSTEMS ENGINEERING
Research Center

Linking Mission & System Level Modeling with Component Level Parametric/Physics Based Modeling



Use Case "Full Stack"

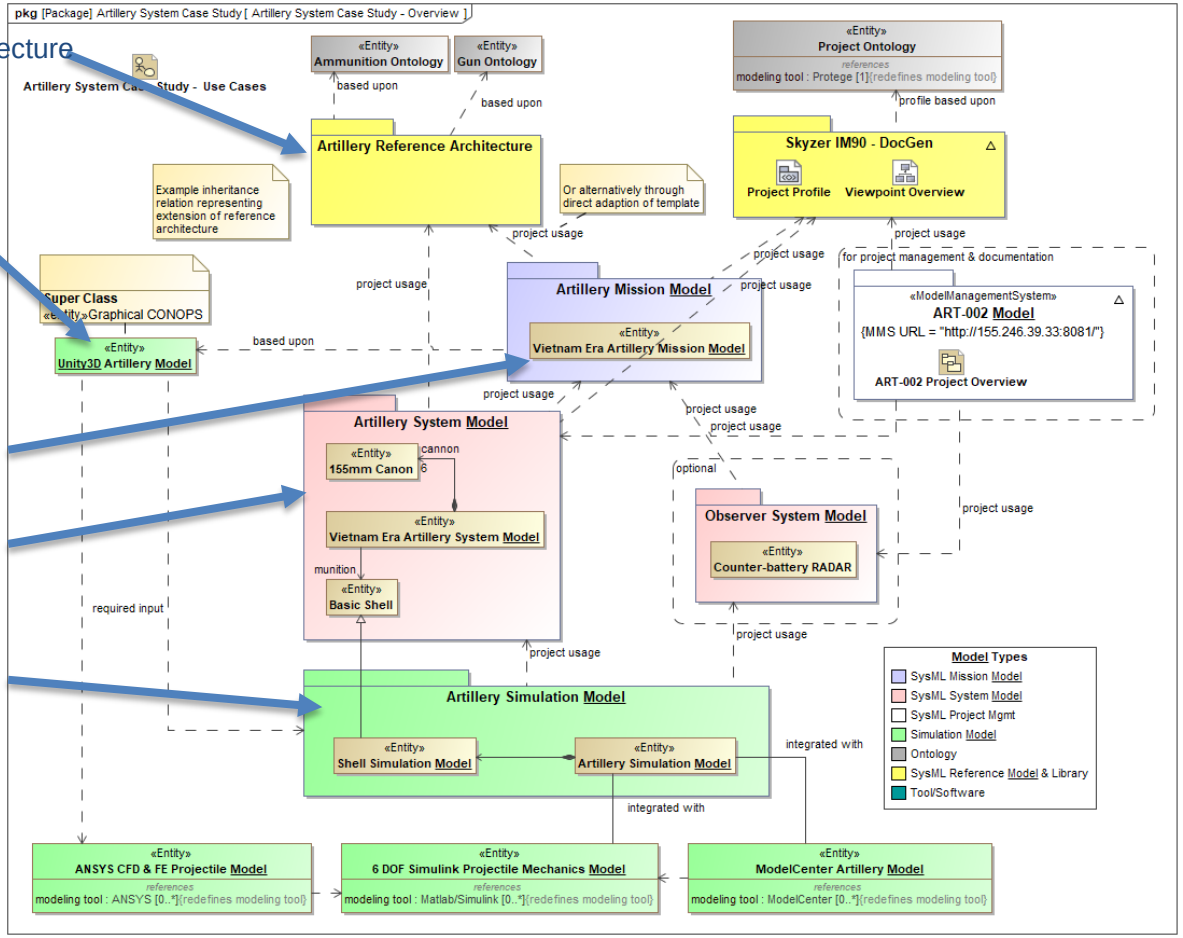
Reference Architecture
(no longer based on ASRM/NAVSEM)

CONOPS

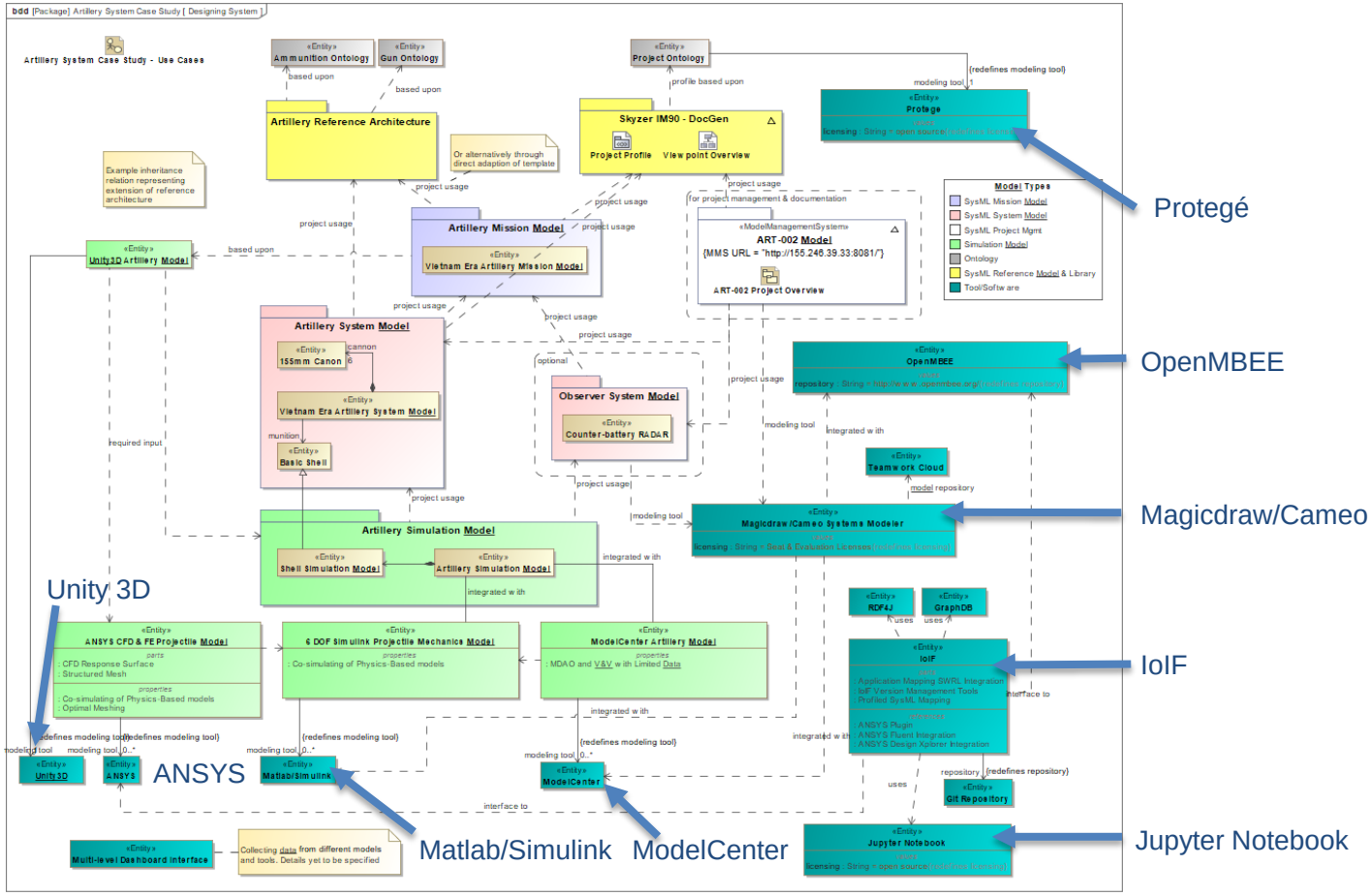
Created Mission Model
(using custom profile)

System Model
(with displayed example model elements)

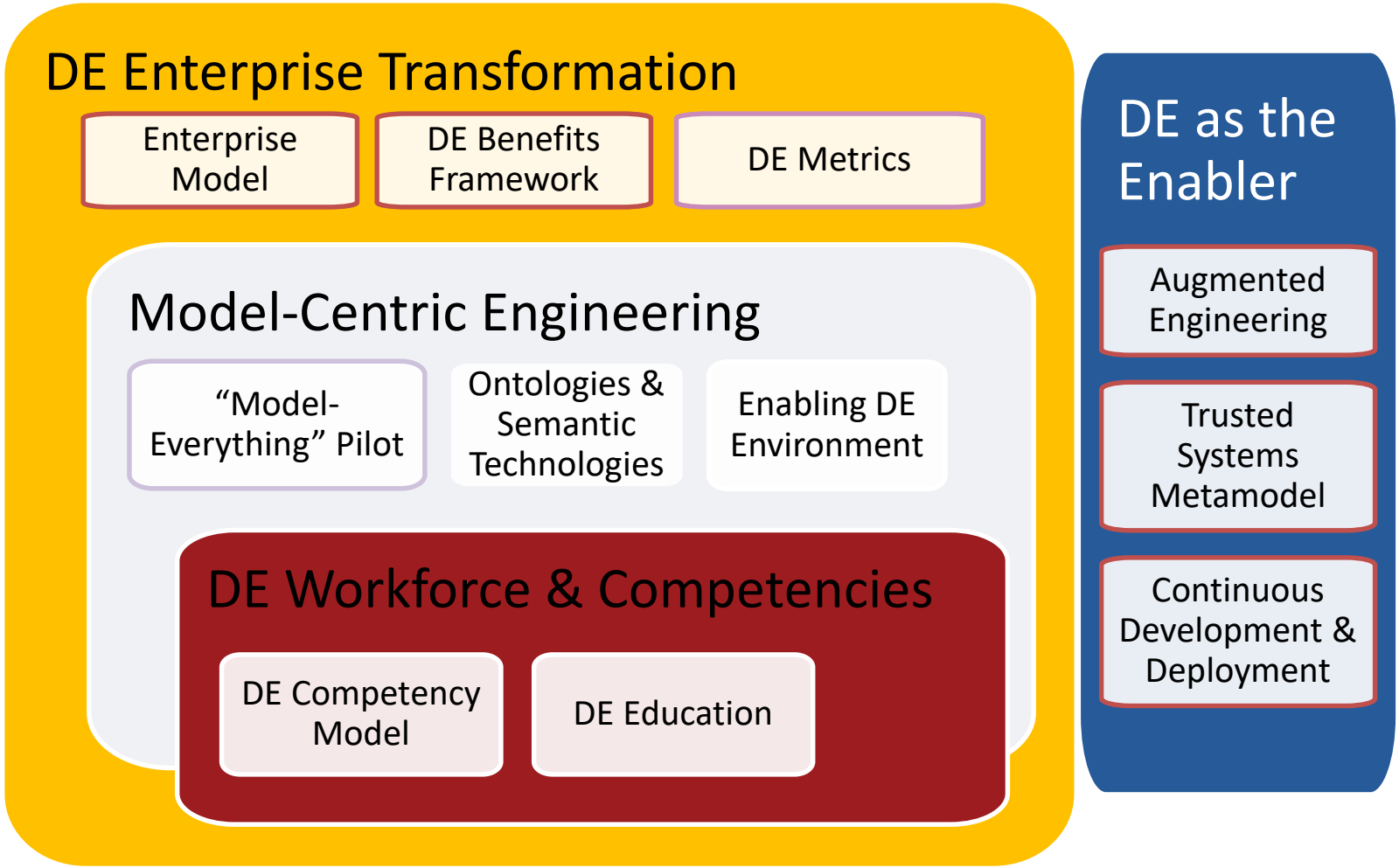
Separate SysML Analysis Model
(by John D.)



Use Case Designing System



SERC Digital Engineering Research

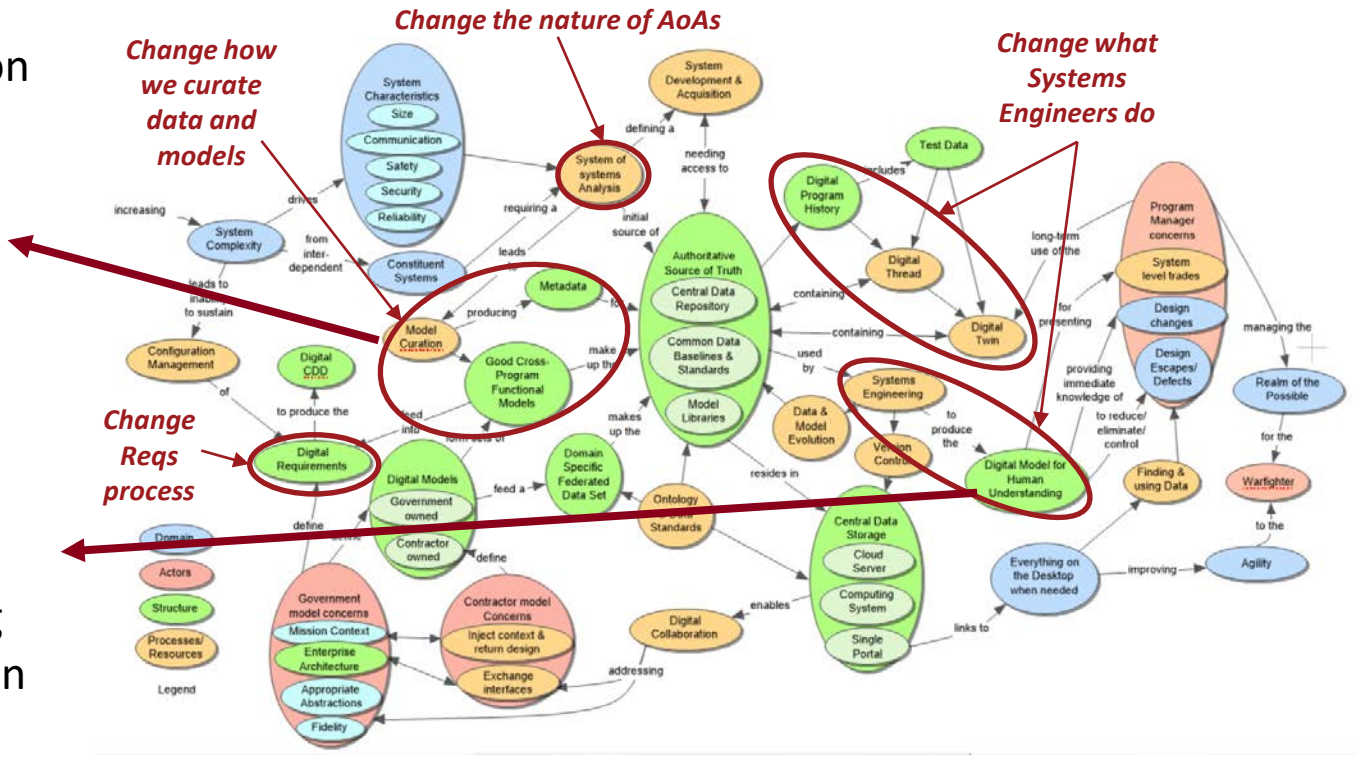


How do we know if an organization has adopted Digital Engineering?

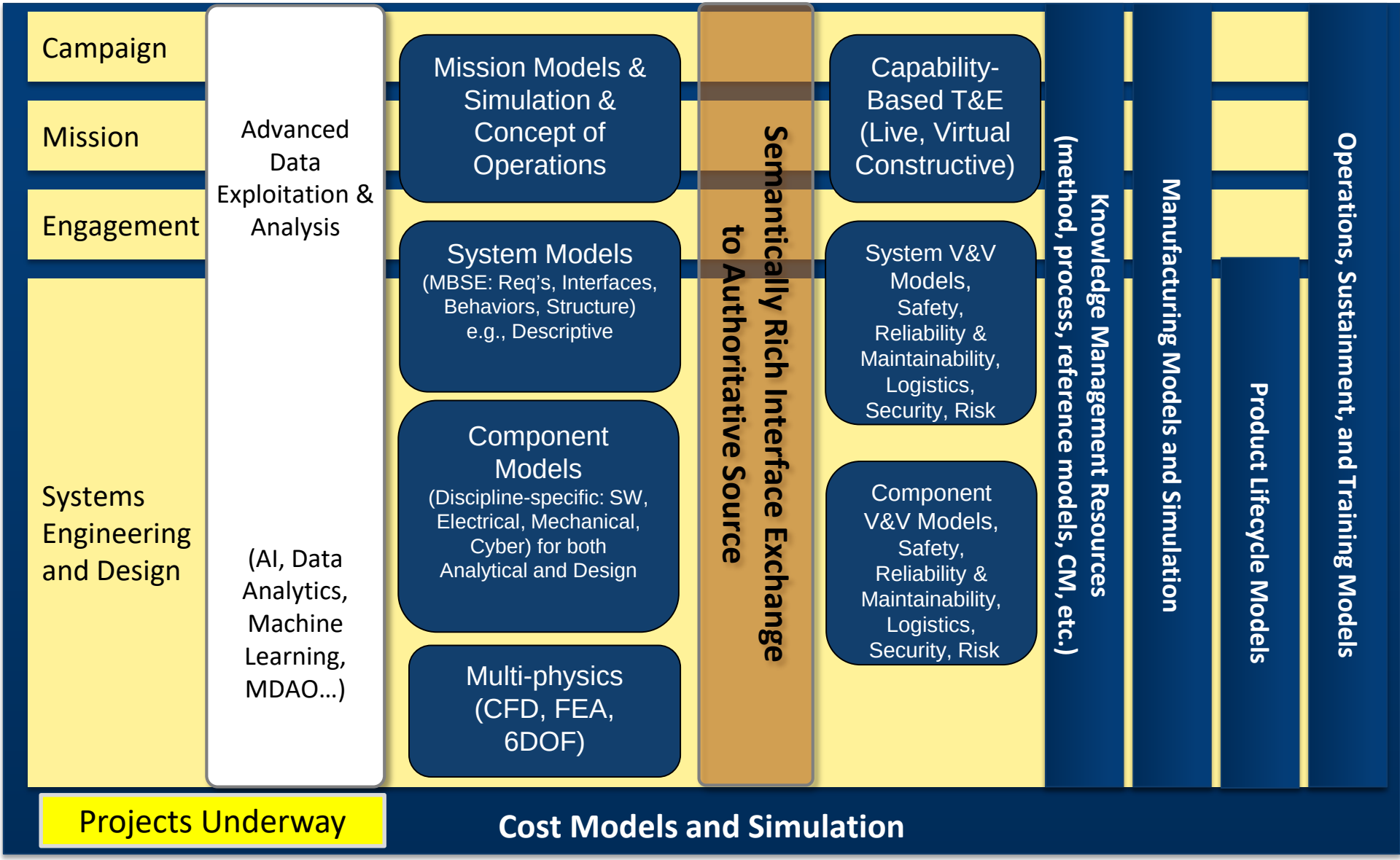
- It has a documented business strategy for use of models/digital artifacts and top-down executive level support for Digital Engineering transformation
- It has an established infrastructure for a Collaborative Integrated Modeling Environment (IME) and the associated Authoritative Source of Truth (AST)
  - Well defined model management processes. This includes methods, methodologies, tools and licenses, a model curation activity, and model exchange practices
  - Established model quality assurance (validation, issue tracking, and improvement)
  - Established means for linking descriptive system models with discipline specific models
  - Established procedures in place for conducting model and modeling reviews directly in the IME and AST across disciplines and across customers/suppliers
  - Established means for generating stakeholder role-specific views directly from the AST
- Established policies and procedures for using models/digital artifacts for contracting and contract deliverables (including procedures for dealing with data rights and IP rights)
- Established workforce development based on modeling methods using case studies in business relevant domains of interest

Enterprise Modeling of the DoD Digital Information Exchange Process

- Conceptually modeled the 5 goals of the DoD Digital Engineering Strategy to identify necessary acquisition enterprise changes
- Current research projects:
  - DE Metrics (WRT-1001) determine critical ROI measures and improved SE value indicators
  - Model Curation (WRT-1009) curation practices, enablers, and technical innovation opportunities
  - DE Workforce (WRT-1006) DE competency model for DAU
  - DE Policy – building model using DocGen



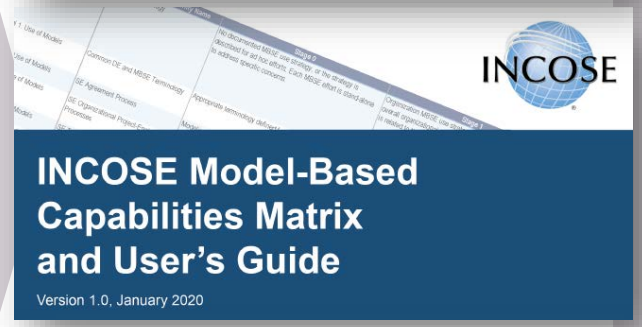
Reference Architecture for an IME in support of Digital Engineering

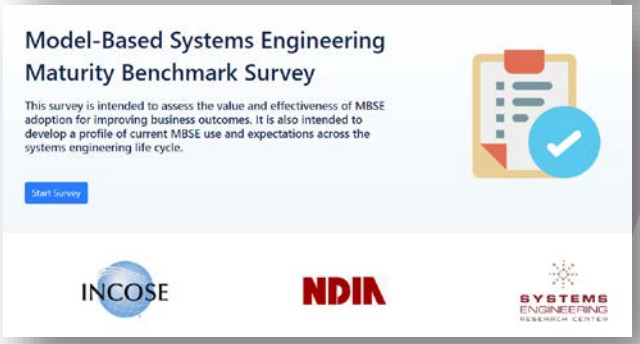


SERC Research Program on DE Metrics & Competencies

Pain Points

Adoption, Capabilities, Benefits





Frameworks

DE Metrics Framework: Digital Engineering Value, Benefits, and Adoption

DE Competencies Framework: Digital Engineering, Digital Analytics, AI & Machine Learning

SYSTEMS ENGINEERING RESEARCH CENTER

Summary DE Success Measures Framework

Models are used to inform enterprise and program decision making	An enduring, authoritative source of truth is used over the lifecycle	Use technological innovation to improve engineering practices	Infrastructure and environments support improved communication and collaboration	Transform culture and workforce engineering across the lifecycle

Quality:
- Reduce Errors/Defects
- Improve System Quality
- Improve Traceability
- Reduce Cost

Knowledge Transfer:
- Better access to information
- Better communication/ info sharing
- Collaboration

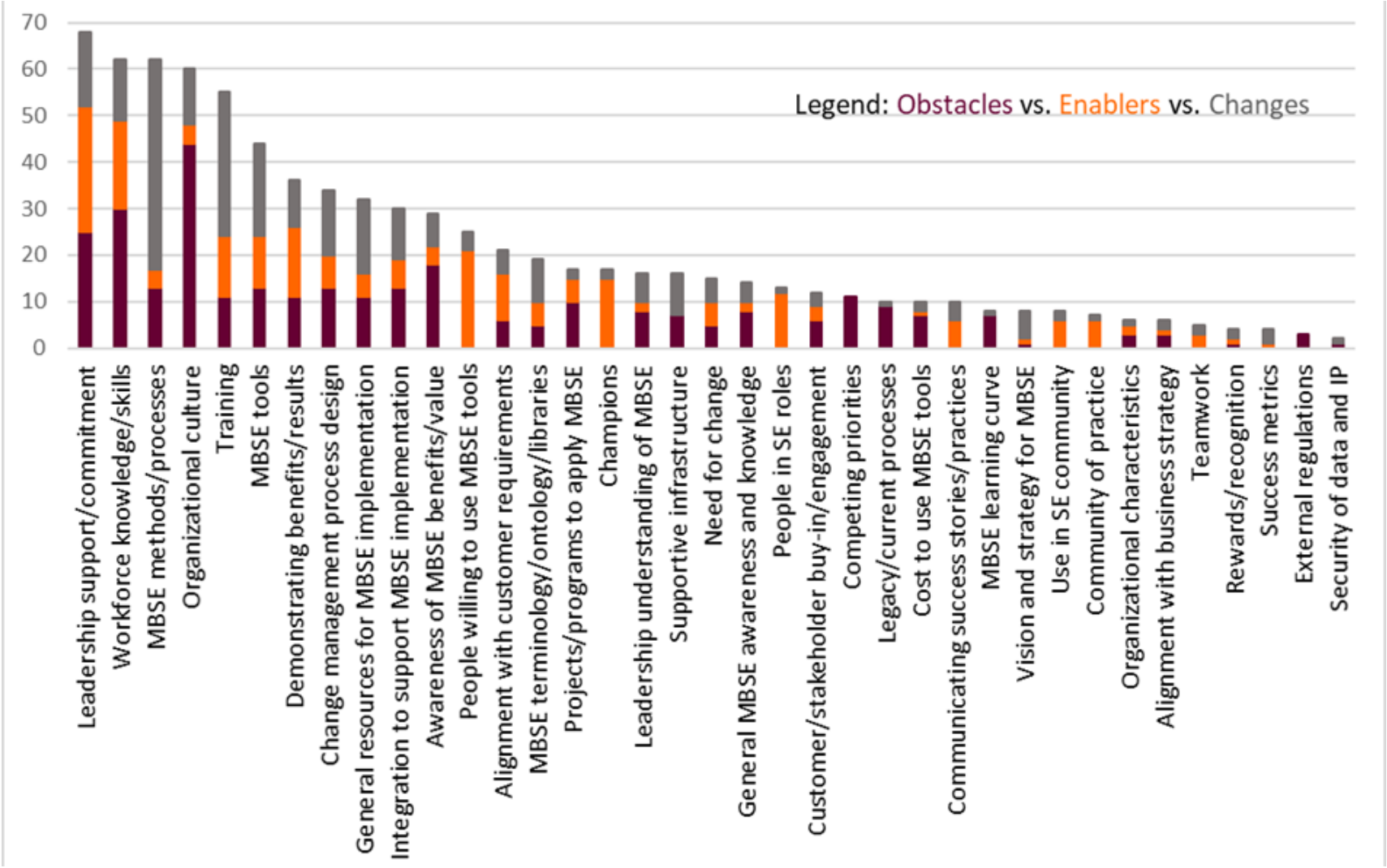
Velocity/Agility:
- More Reuse
- Improve Consistency
- Increase Efficiency
- Support Integration
- Reduce Time

User Experience:
- Manage Complexity
- Improved System Understanding
- Automation

Adoption:
- Methods/Processes
- Roles/Skills
- Training/Tools
- Leadership support
- Change Mgmt Process
- Resources

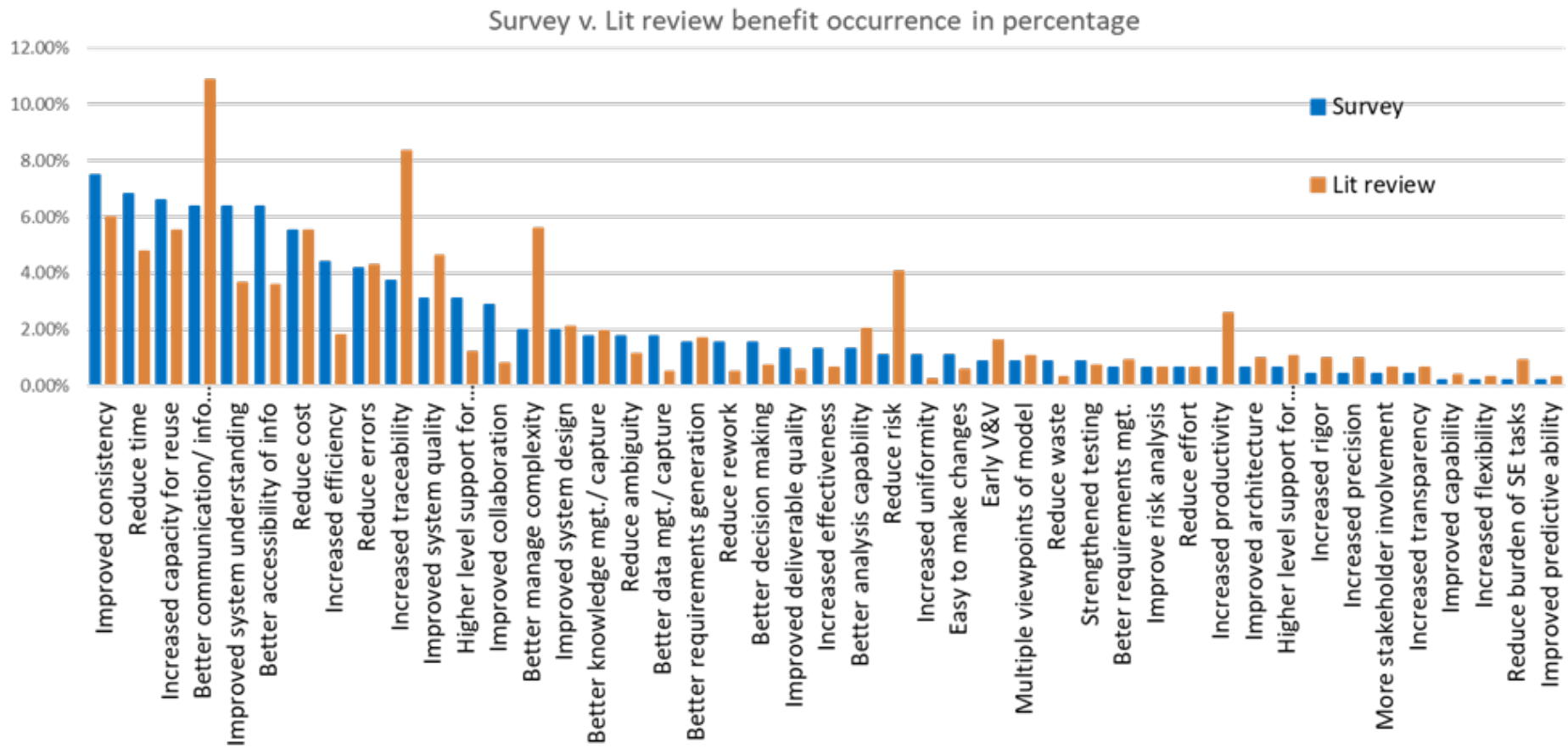
Study Data: DE Adoption

Obstacles, Enablers, and Changes for DE Adoption, ranked by Frequency of Mention



Study Data: DE Benefits

Top Cited DE Benefits Areas from Literature and Survey Results



Download Results

https://sercuarc.org/results-of-the-serc-incose-ndia-mbse-maturity-survey-are-in/

June 8, 2020 – Summary Report Task Order WRT-1001: Digital Engineering Metrics Supporting Technical Report SERC-2020-SR-003

View the DE Metrics Summary Report (June 8, 2020)

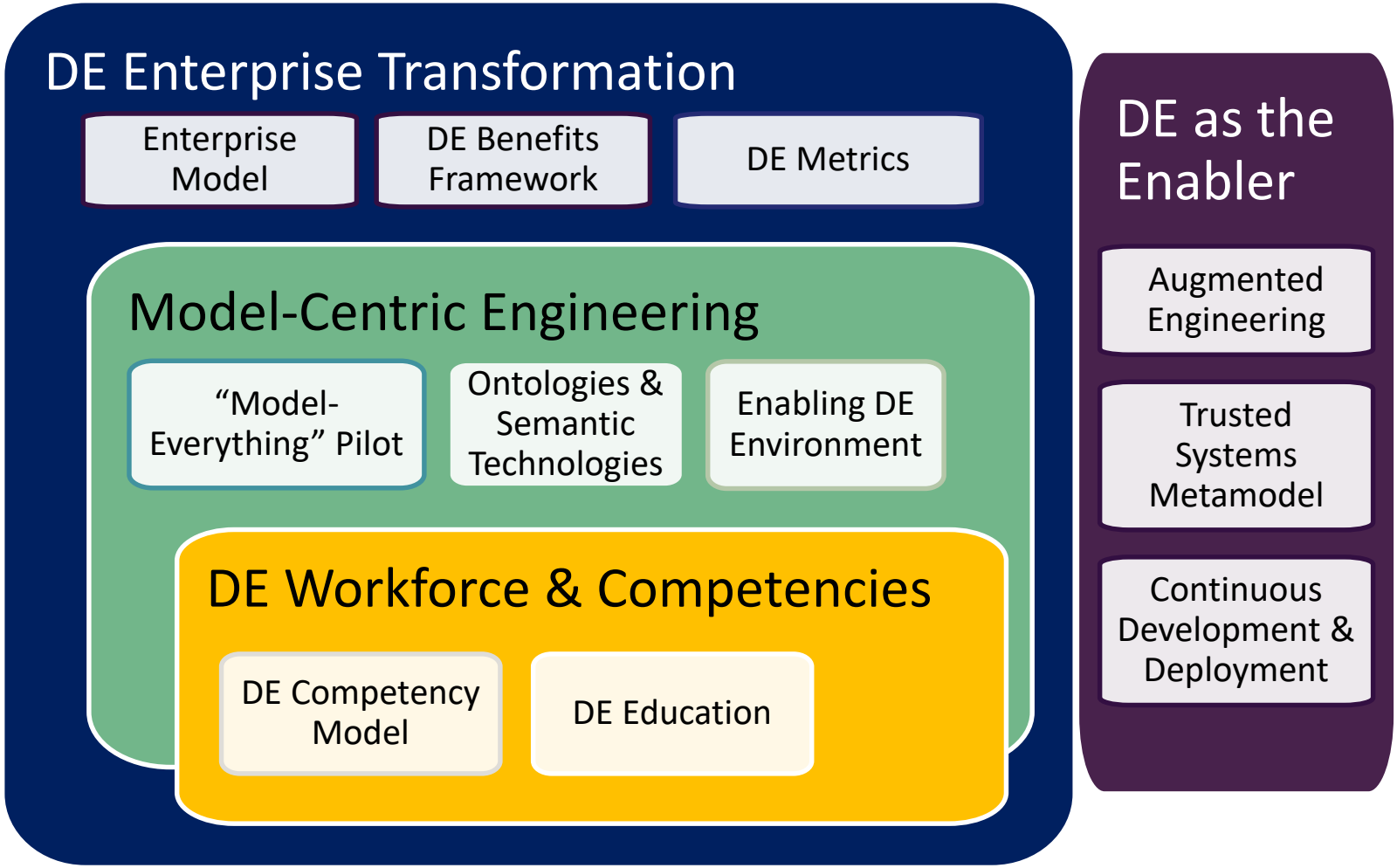
March 19, 2020 — Benchmarking the Benefits and Current Maturity of Model-Based Systems Engineering across the Enterprise Results of the MBSE Maturity Survey / Part 1: Executive Summary

View the SERC-2020-SR-001 report on the results of the MBSE Maturity Survey

June 8, 2020 – Task Order WRT-1001: Digital Engineering Metrics Technical Report SERC-2020-TR-002

View the Digital Engineering Metrics Full Technical Report

SERC Digital Engineering Research

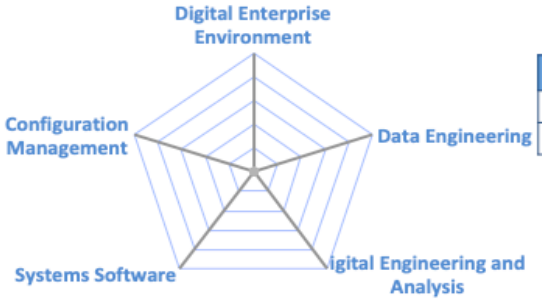


Digital Engineering Competency Framework (DECF)

There are 5 competency groups and 22 competencies identified for the DECF

1. Digital Enterprise Environment		
Digital Enterprise Environment Development	1	Digital Environment Development
Digital Enterprise Environment Management	2	Management
	3	Communications
	4	Planning
Digital Enterprise Environment Operations and Support	5	Digital Environment Operations
	6	Digital Environment Support
Digital Enterprise Environment Security	7	Digital Environment Security

5. Configuration Management	
22	Configuration Management



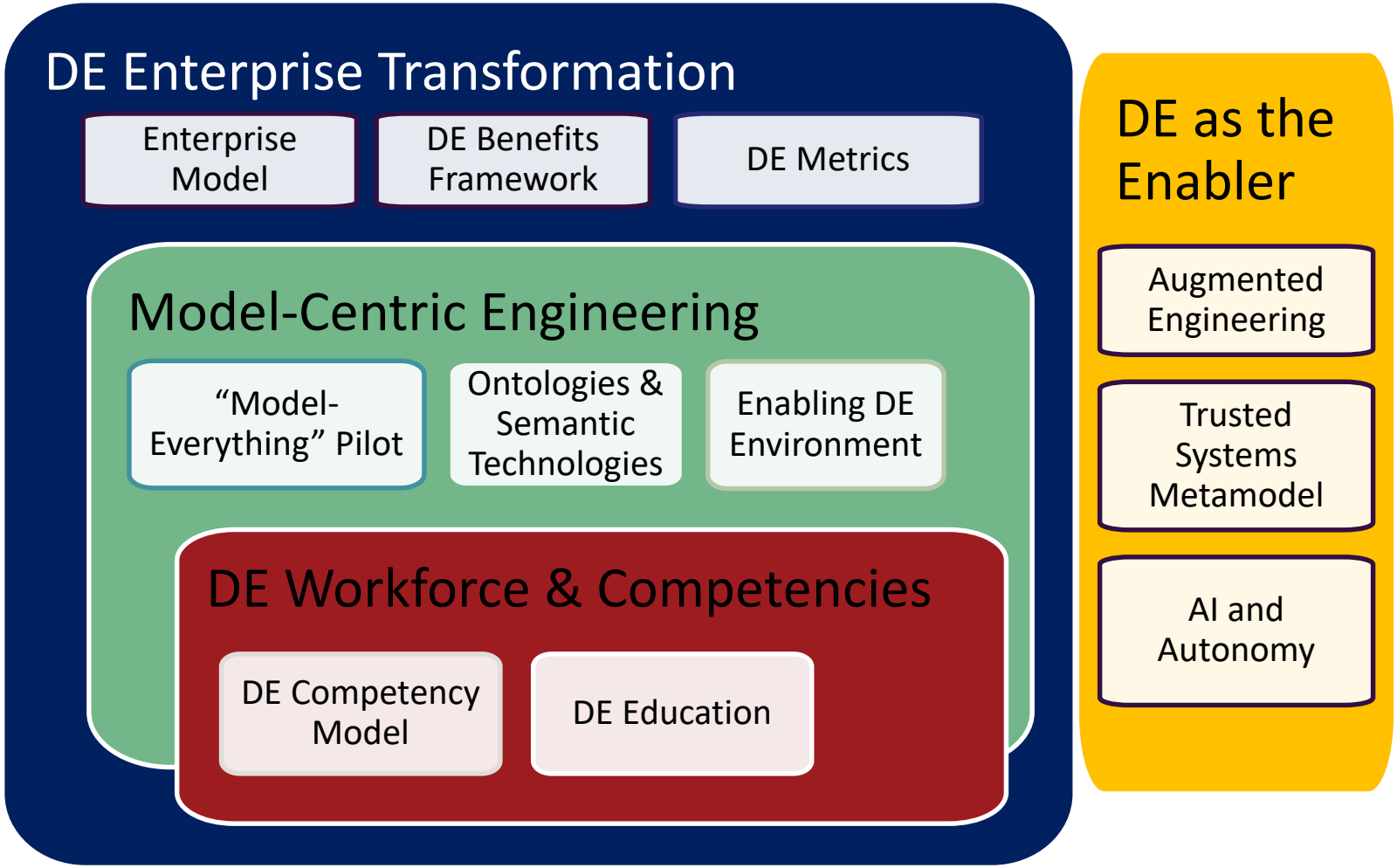
2. Data Engineering	
8	Data Governance
9	Data Analytics

4. Systems Software	
20	Software Construction
21	Software Engineering

3. Digital Engineering and Analysis		
Modeling, Simulation, and Analysis	10	Modeling, Simulation, and Analysis
Coaching and Mentoring	11	Coaching and Mentoring
Systems Engineering	12	Model-Based Systems Engineering Process
	13	Digital Architecting
	14	Digital Requirements Modeling
	15	Digital Verification
Systems Engineering Management	16	Digital Model-Based Reviews
	17	Project Management
	18	Organizational Development
	19	Digital Engineering Policy and Guidance

Foundational Digital Competencies

SERC Digital Engineering Research



Standard SE Process Methodology for Designing Resilience into Cyber-Physical Systems

System Model

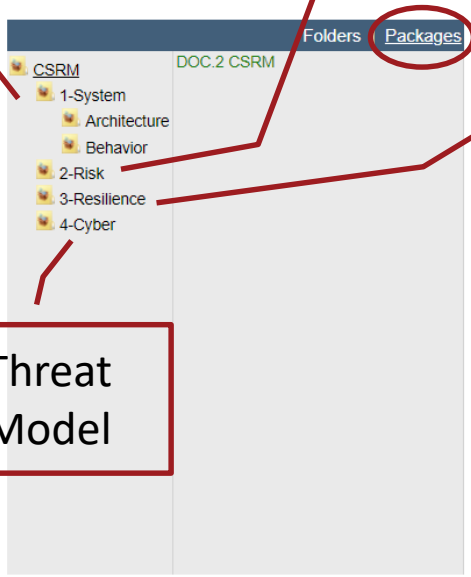
Assurance Model (STPA)

System Aware Model (Resilience modes and Sentinel patterns)

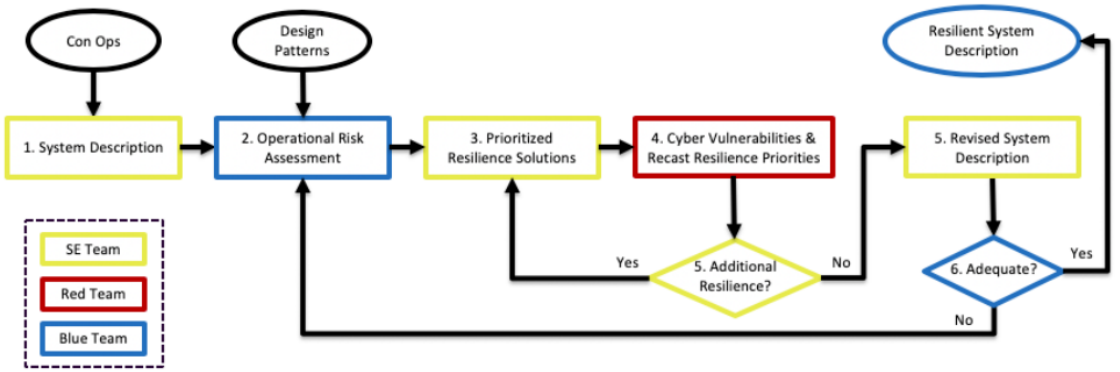
Threat Model

MISSION AWARE

Project: ART-004: Pipeline - Metrics Project
Contact: Tim Sherburne
Powered By GENESYS. Generated 14 February 2020.



Cyber-Security Requirement Methodology (CSRM)



Select "Packages" -> "CSRM" to navigate model per CSRM Steps
NOTE: click package icon to expand section

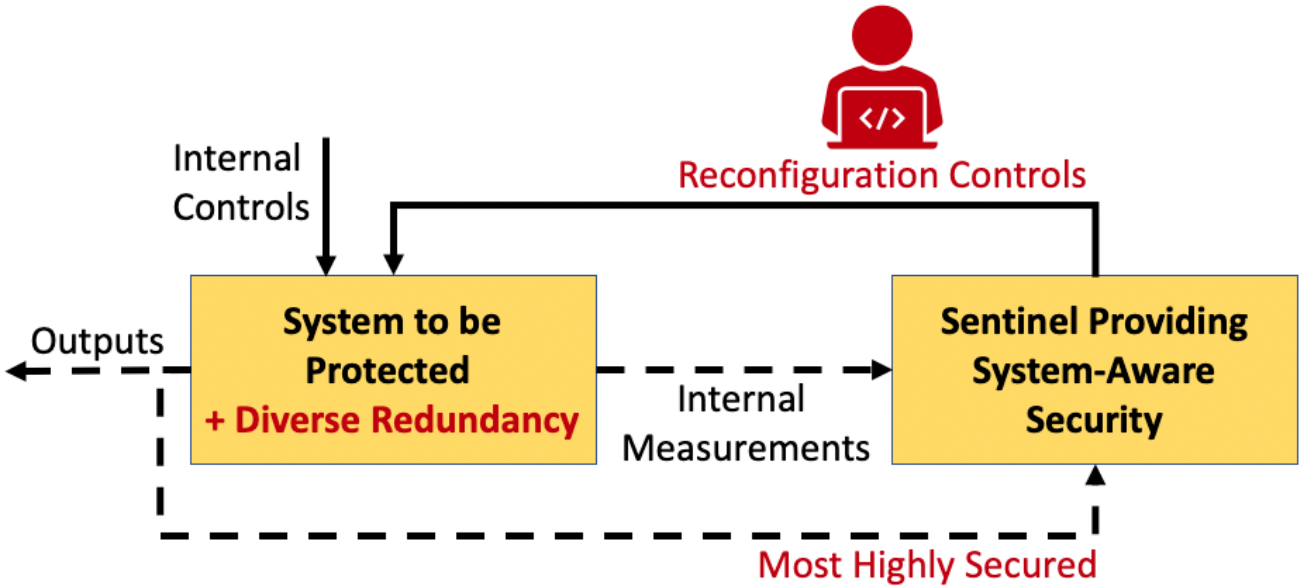
Ready for Transition

Project: ART-004: Pipeline - Metrics Project

Mission Aware Cyber Resilience

- System design for **Resilient Modes**: distinct and separate methods of operation of a component, device, or system based upon common resilience design patterns such as diverse redundancy.
- System monitoring via a **Sentinel** design: another design pattern responsible for monitoring and reconfiguration of a system using available Resilient Modes.

SERC has demonstrated the effectiveness of these patterns in live red team testing of UAVs, Automobiles, 3D printers, and Military armament



Transitioned

Key AI/Autonomy Research Goals

- **AI for SE:** AI/ML to support the practice of SE
  - —Support scale in digital model construction
  - —Create confidence in design space exploration
- **SE for AI:** SE approaches to systems with AI/ML capabilities
  - —Principles of learning-based systems design
  - —Models of life cycle evolution, Model curation methods
- **Lifecycle Ready AI:**
  - —AI-related agility: new SE methods and tools that anticipate adaptation
  - —Technical and management policies that assure lifecycle-ready AI
- **Systems Validation of AI:**
  - —Early visibility for deployment, validation of post-deployment changes
  - —System level testbeds – to study systems, not just data & algorithms

In Closing: Thanks!

- Thanks for inviting me to be a part of this year's Model Based Space Systems and Software Engineering Symposium – MBSE2020. I really wish we could have done this in person;
- Given the unique nature of this year's Symposium, please feel free to reach out to me at dinesh.verma@stevens.edu if you have any follow up questions or interest in any of the research projects reviewed in this briefing.