SYSTEMS ENGINEERING RESEARCH CENTER

AIRC ACQUISITION INNOVATION RESEARCH CENTER

SYSTEMS ENGINEERING RESEARCH CENTER (SERC)
ACQUISITION INNOVATION RESEARCH CENTER (AIRC)

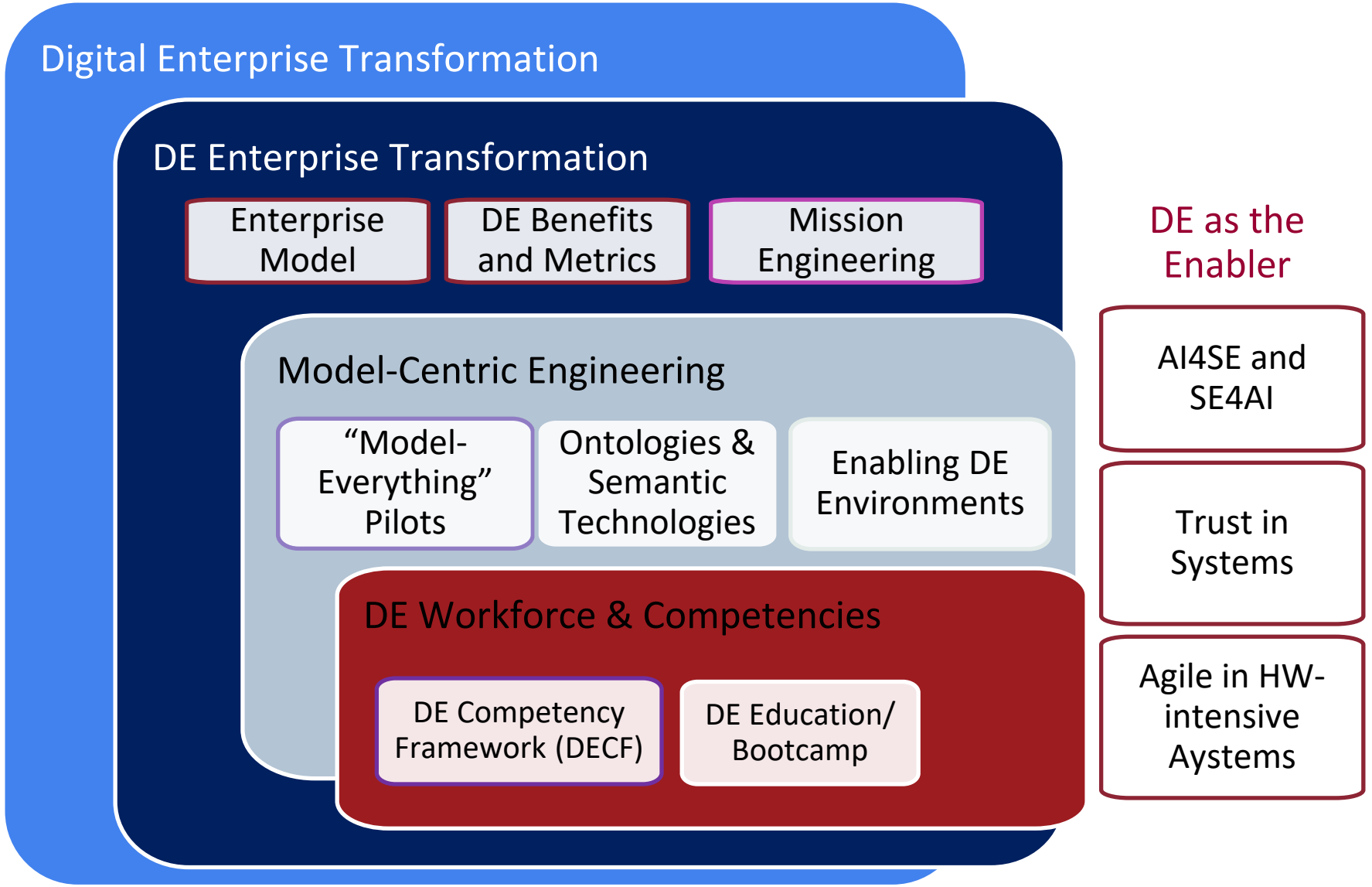
10 YEARS OF DIGITAL ENGINEERING RESEARCH AND EXPERIMENTATION

Tom McDermott, Chief Technology Officer, SERC

Stevens Institute of Technology, Hoboken, NJ 07030

OUTLINE

1. Who we are
2. 10 Years of DE Research, Experimentation, & Demonstration



SERC/AIRC UARC History

SERC – Systems Engineering Research Center

- In 2008, DoD competitive request for a University Affiliated Research Center (UARC) on systems engineering
- Stevens Institute of Technology led a team that brings 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 Sept. 2008
  - Vested through a 5-year renewable task order based IDIQ contract (current 2018–2023); Renewal for the next 5 years currently underway.

AIRC – Acquisition Innovation Research Center

- A new center under the existing SERC UARC, added on September 30, 2020
  - Statutory directive from Congress in the 2020 National Defense Authorization Act (NDAA).
  - Expands SERC focus to all of acquisition
    - —Systems engineering is one of many critical functions and disciplines within acquisition

SERC/AIRC is unique among UARCs

- Only UARC funded at the DoD OSD level: USD(R&E)
- Reach to a collaborative network of 22+ universities – A National Network versus a Large University
- Address all government acquisition and systems engineering: education, research, and practice

SYSTEMS ENGINEERING RESEARCH CENTER

AIRC ACQUISITION INNOVATION RESEARCH CENTER

A MULTI-UNIVERSITY PARTNERSHIP

Ohio St., George Washington, George Mason, Univ. Arizona, and North Carolina St. will join the SERC/AIRC Network later in 2024 as we go through our renewal.

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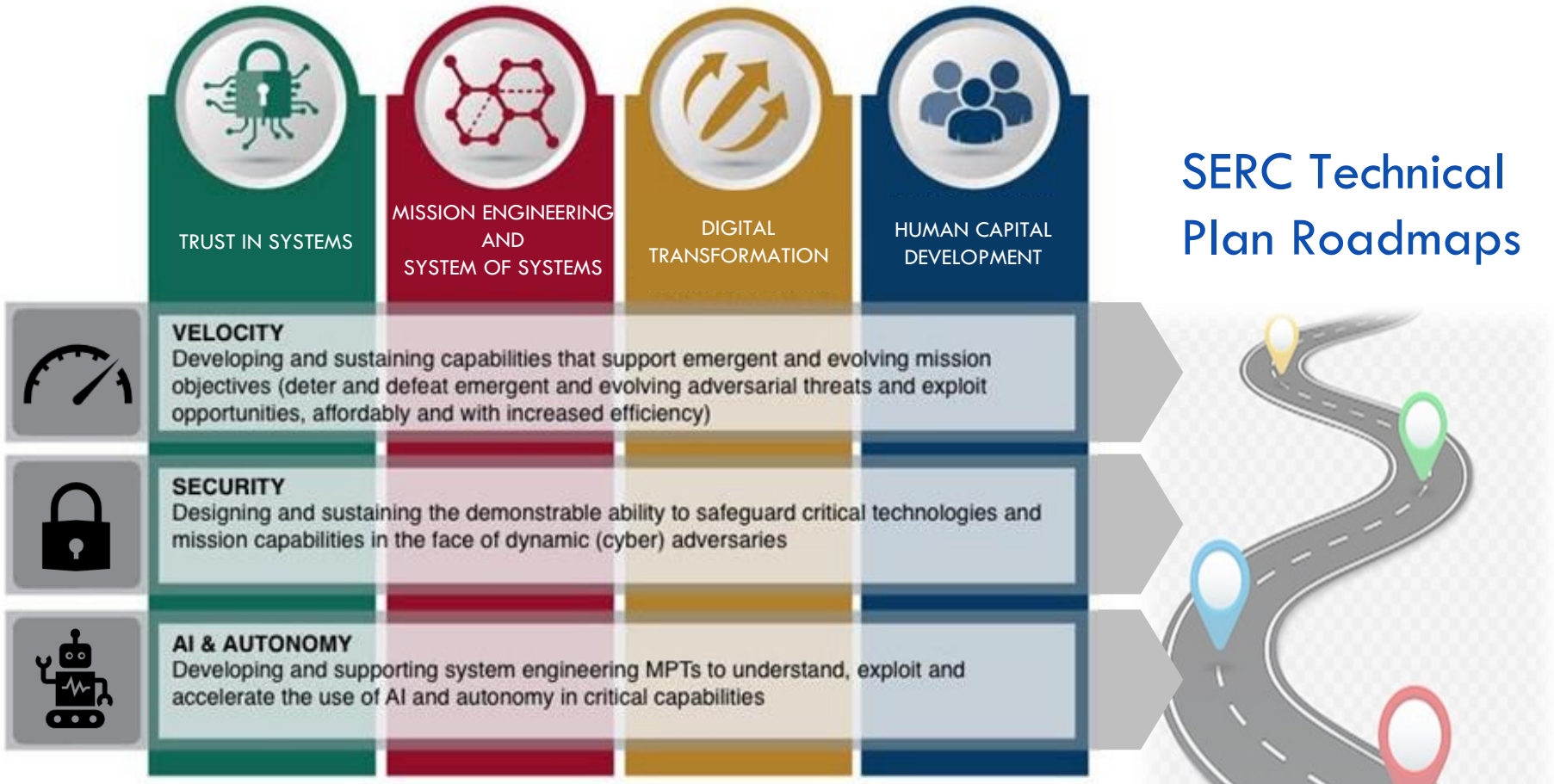
SERC Research Areas and Missions

Mission Engineering/Portfolio Based Analysis



SERC Technical Plan Roadmaps

Digital Engineering/Semantic Interoperability – Domain Disciplines

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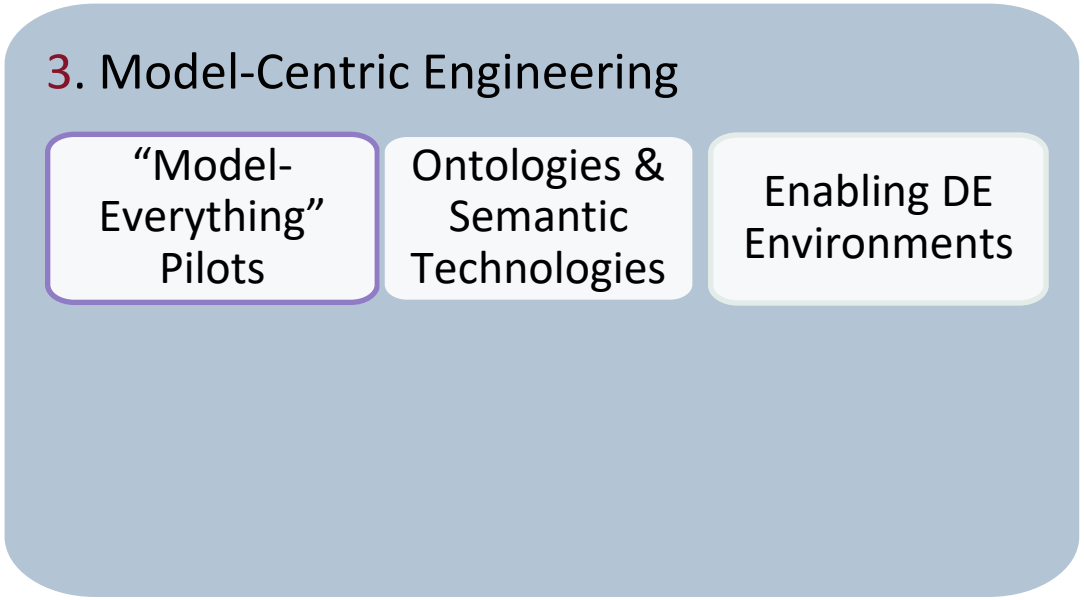

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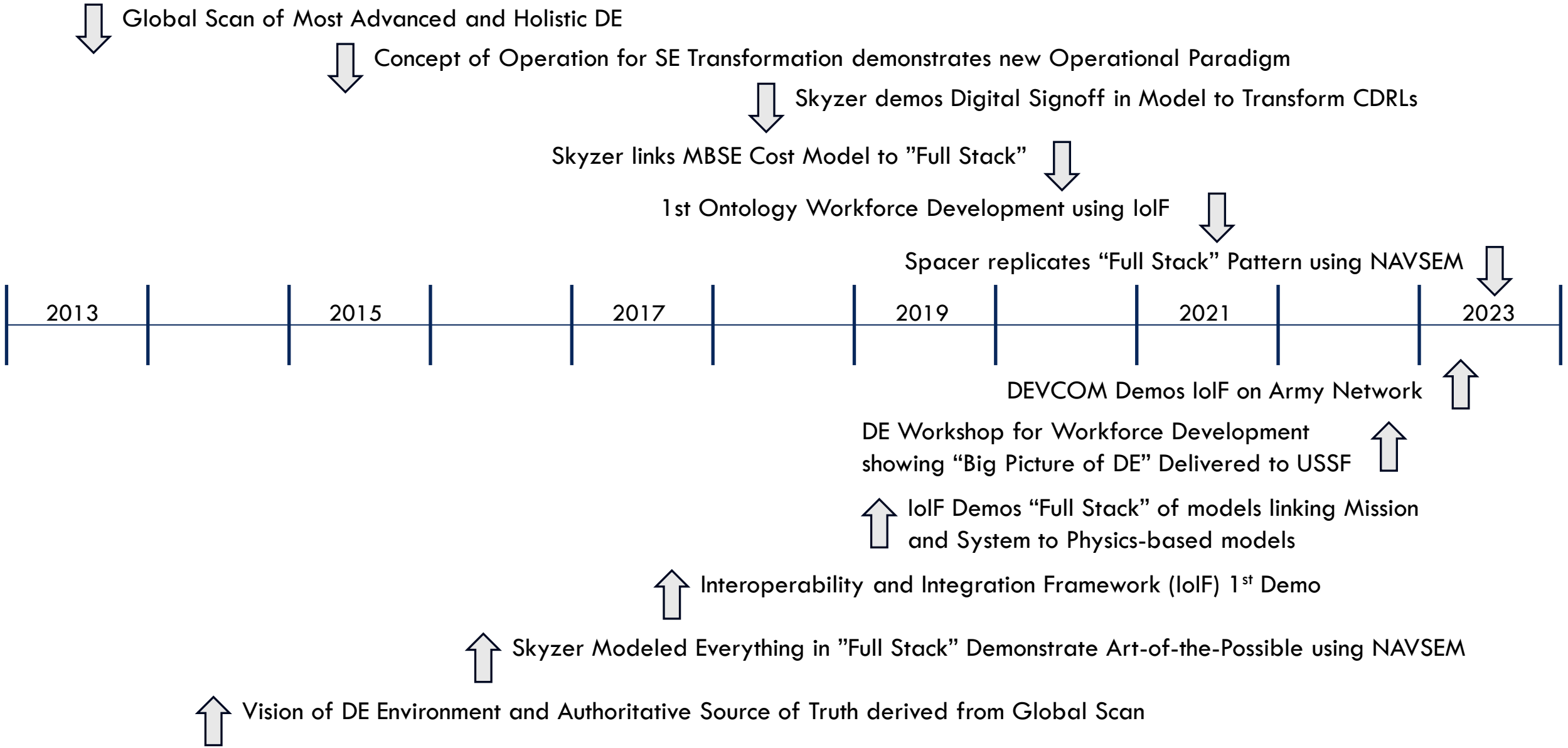
10 YEARS OF DE RESEARCH, EXPERIMENTATION AND DEMONSTRATIONS OUTCOMES(NON-EXHAUSTIVE)



10 YEARS AGO: LEADERS WERE EMBRACING CHANGE AND ADAPTING TO USE DIGITAL STRATEGIES FASTER THAN OTHERS

⇩ 2013: Global Scan of Most Advanced and Holistic DE

1. Enabling digital technologies are changing how companies are doing business using model-centric engineering (now Digital Engineering)
2. They use model-centric environments for customer engagements, and also for design engineering analysis and review sessions
3. Use commercial technologies and have developed a significant amount of infrastructure on their own
4. We heard about mission-level simulations that are being integrated with system simulations, digital assets & products providing a new world of services

DEMONSTRATING NEW DE WORKFLOWS IN OPEN PROJECT SETTINGS

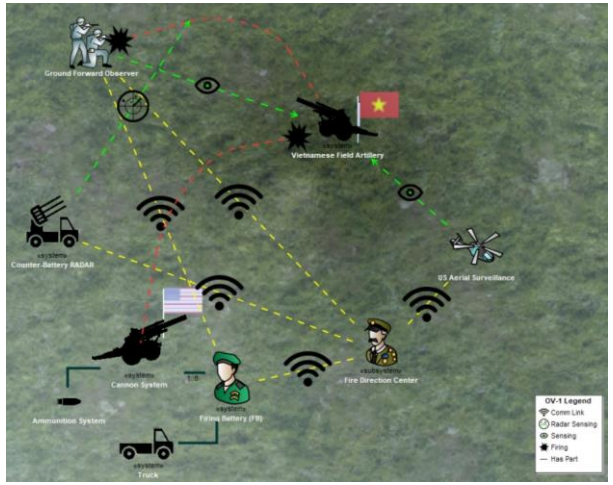
2016: Skyzer Modeled Everything in "Full Stack" Demonstrate Art-of-the-Possible using NAVSEM

2017: DEVCOM Demos IoIF on Army Network

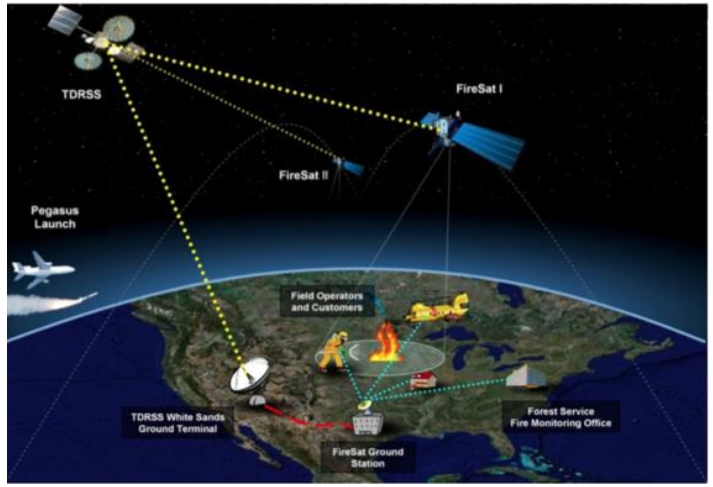
2023: Spacer replicates "Full Stack" Pattern using NAVSEM

Skyzer Search & Rescue

Armaments Missions



Spacer: FireSat



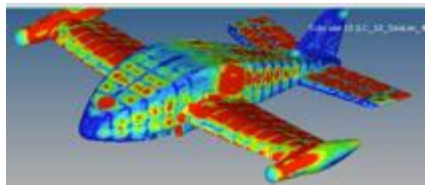
Research and Surrogate Experiment contributes broadly to NAVAIR SET Functional Areas

Surrogate Pilot Scenario: UAS Search/Rescue Mission

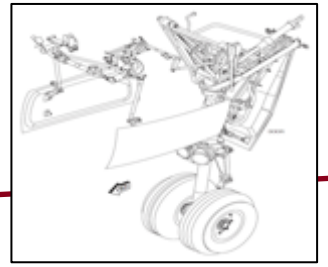
Concept of Operation for SE Transformation demonstrates new Operational Paradigm

Deep Dives by Phases

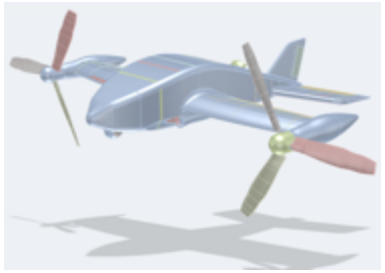
Graphical CONOPS Scenario: Search & Rescue



P1: Multi-physics



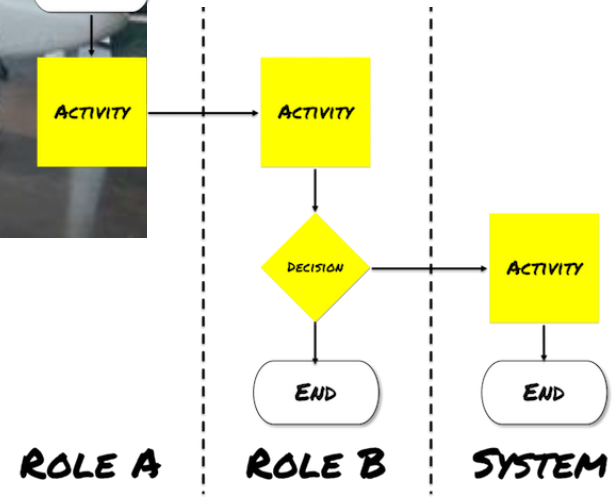
P2: Airworthiness



P3: Cost Modeling

Performance constraints force Multi-physics Design considerations – similar to Bell Eagle Eye

Conform to Navy standard Systems Engineering process model



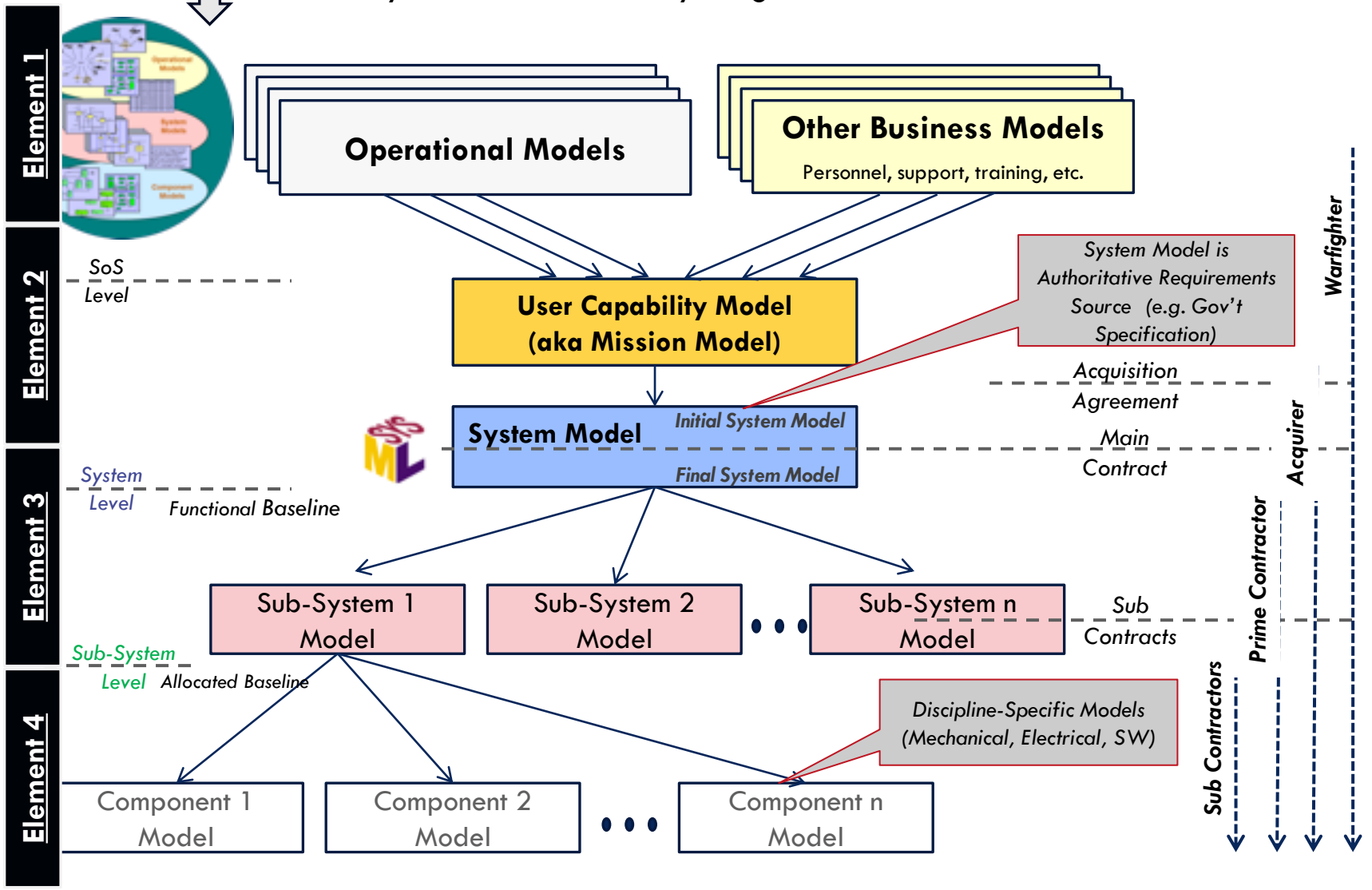
Doing Everything in Models to Demonstrate Art-of-the-Possible

SKYZER DEMONSTRATES MODELING AT DIFFERENT ABSTRACTION LEVELS

2016: Skyzer Modeled Everything in "Full Stack" to Demonstrate the Art-of-the-Possible

MBSE tools & languages applicable

MBE tools & languages applicable



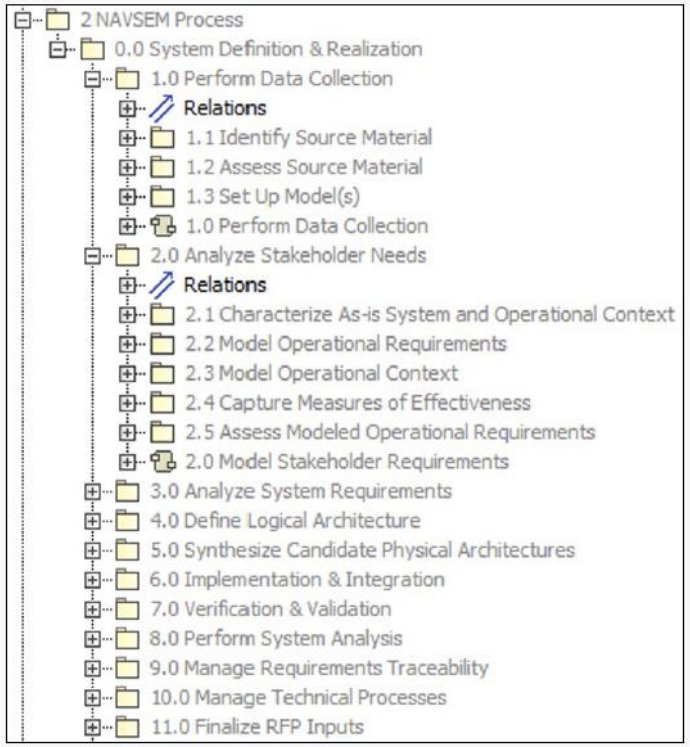
ORGANIZE THE MODEL TO THE SE PROCESS

2023: Spacer replicates "Full Stack" Pattern using NAVSEM ⇩

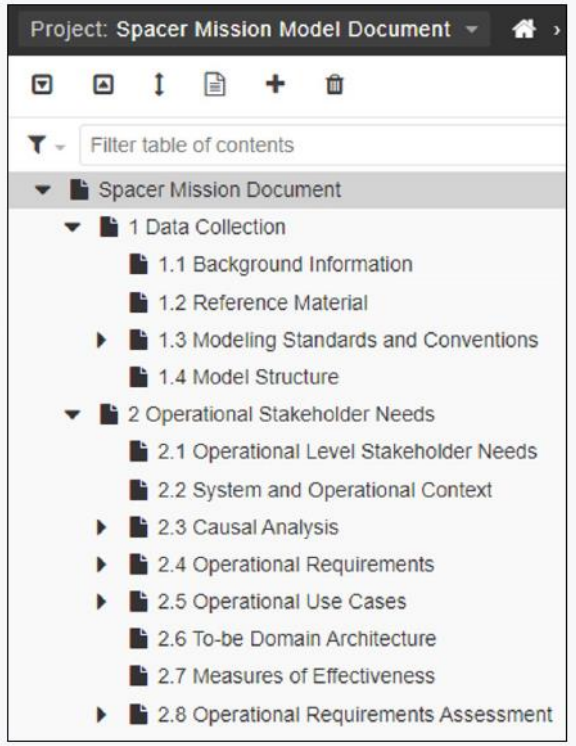
Model's Setup and Compliance with NAVSEM

- Using NAVSEM, models can be setup and organized more efficiently
- Document Models can be used to keep track of compliance with NAVSEM
  - The outline of the Document model is consistent with the NAVSEM process steps
  - If information is missing from an element within the outline, then this tells us model information is missing and thus not yet fully compliant with NAVSEM

Process Steps shown in MagicDraw Containment Tree



DocGen Output in OpenMBEE View Editor web-app



- Spacer Mission Model shown for example
- Spacer Mission Model covers Steps 1 and 2 in NAVSEM

"FULL STACK" OF SKYZER MODELS ENABLES ACQUISITION ANALYSIS

Skyzer links MBSE Cost Model to "Full Stack"

Generalization of Previous Mission/Systems

- Mission Reference Models
- System Reference Models

Using and Tailoring Reference Models

Reference models characterize reusable information and process

- NAVSEM Model
- Airworthiness Model
- CBT&E / MBTD Model
- Cyber Model
- Reliability and Maintainability
- Cost Model
- More…

NAVSEM Compliant

"Full Stack" Skyzer

- Mission Model
- Skyzer System Model

Project Usage

L&R Sys Model

Contractor RFP Response Model

Avionics M…

Airframe

Landing-Gear Subsystem Model

…

Stakeholder Analysis Models

- Instance of CBT&E / MBTD Model
- Instance of Airworthiness Model
- Instance of Cost Model

Criteria focused on Capability-based Test & Evaluation (CBT&E) and Mission-based Test Design (MBTD)

Criteria needed and evidence provided for getting a flight clearance

Cost Modeling approach based on using MBSE artifacts

How to model to develop Authoritative Source of Truth

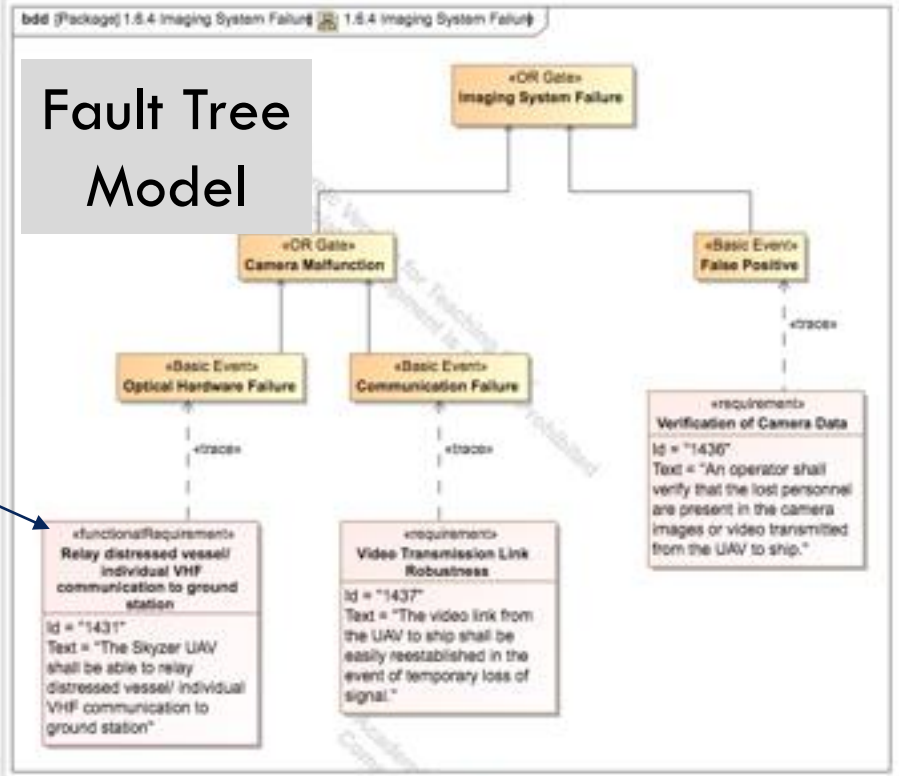
DIGITAL SIGNOFFS ARE TEMPLATE-BASED & TAILORABLE TO SUBJECT MATTER EXPERTS

Skyzer demos Digital Signoff in Model to Transform CDRLs

TABLE III. Risk assessment matrix

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Mitigation Requirement to address Basic Events that could lead to Mishap for the Hazard



9.2 System Failure Analysis Signoff

Last Modified: 5/13/20 9:36 AM by ben

EXPORT CSV FILTER TABLE

Table 176. System Failure Analysis Signoff

Approved Elements	Approval Status	Approved By	Completeness	Probability	Impact	Comment
3.9 Fault Tree Analysis	Value : rejected ADD	Adam Baker	Value : 75 ADD	Value : 25 ADD	Value : 75 ADD	may need an extra basic event added

Fault Tree analysis is the Model Artifact being assessed for a potential hazard, and assessment of Completeness, Probability and Impact is captured with Approval Status for Digital Signoff by SME

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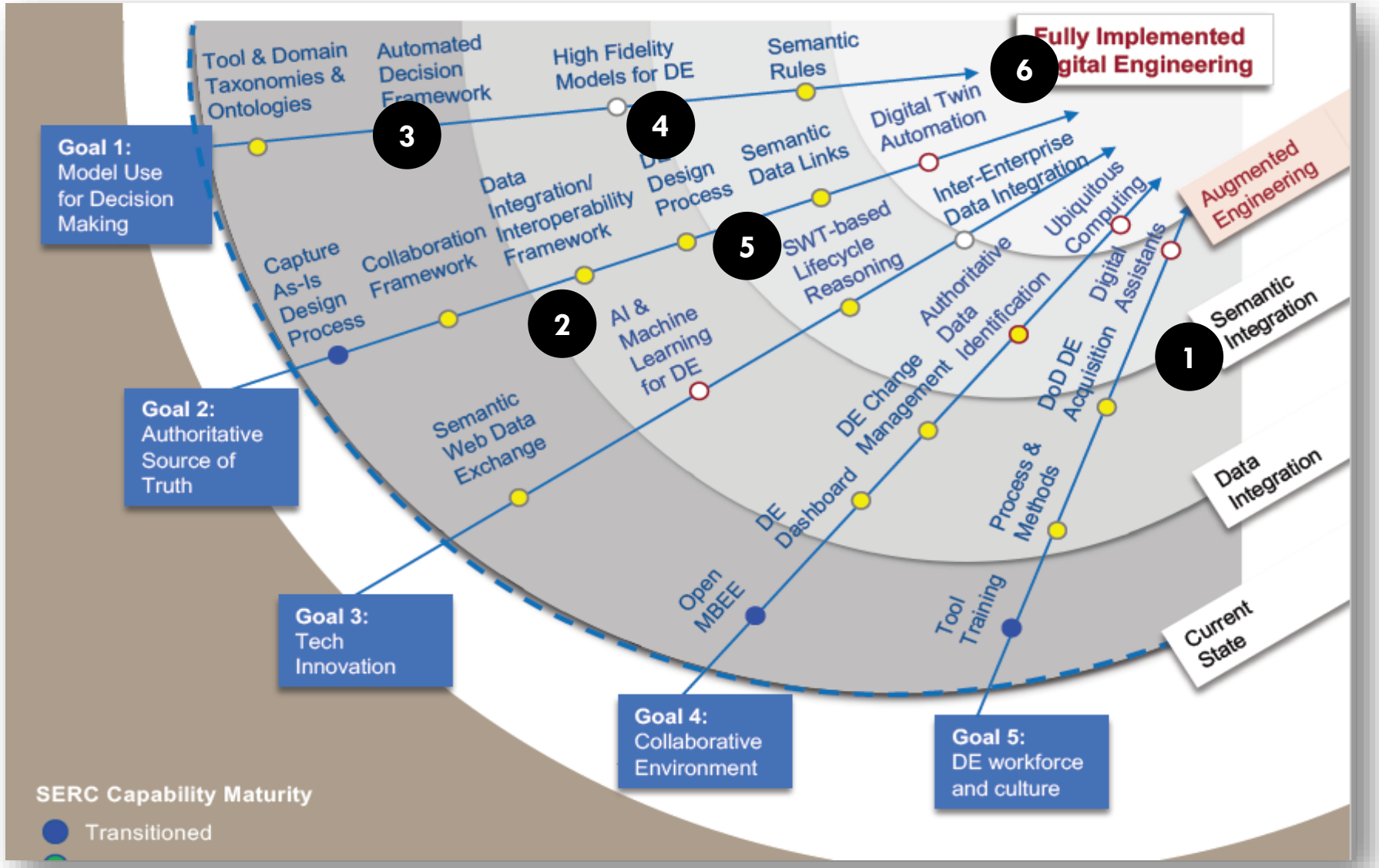
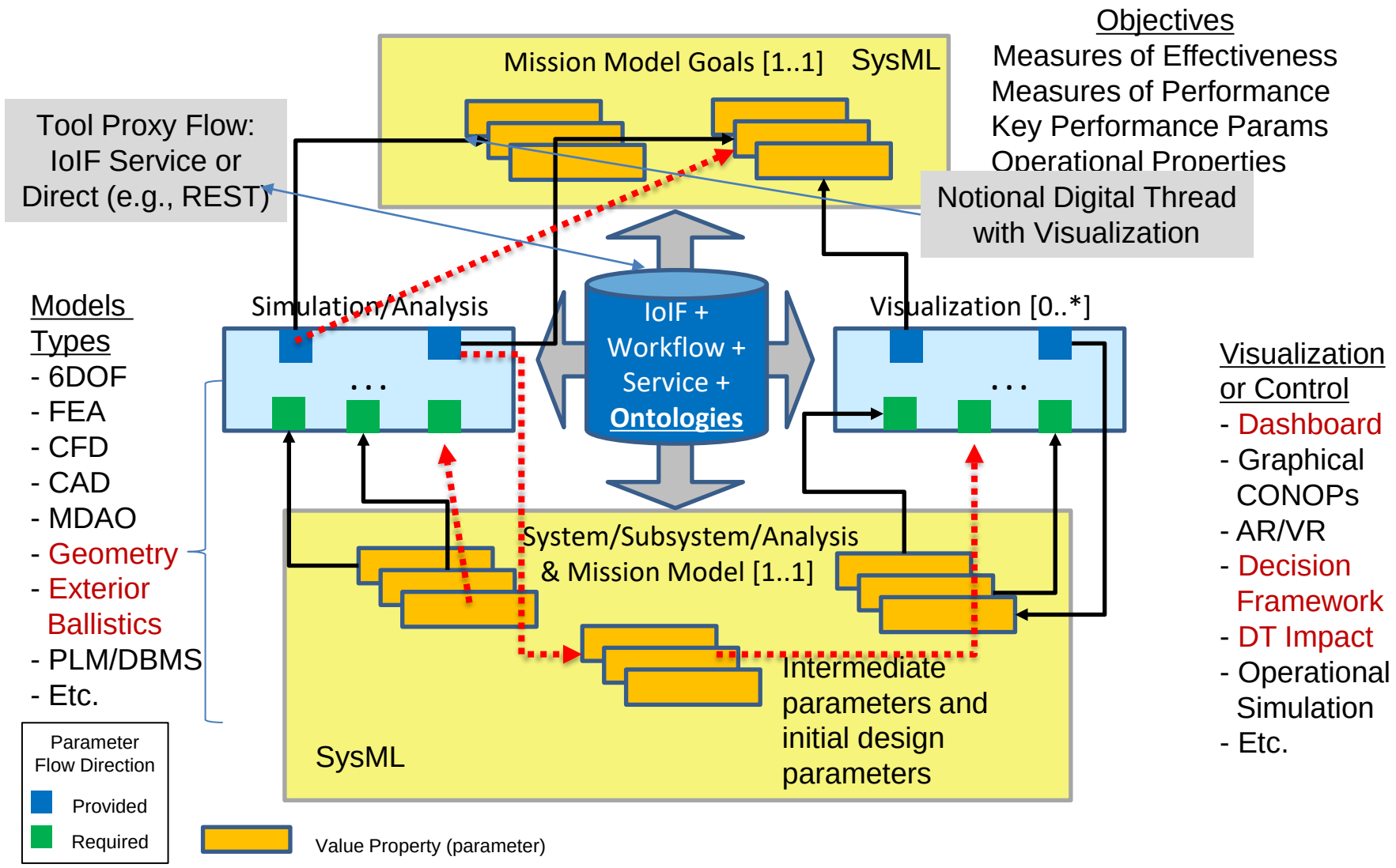
DIGITAL ENGINEERING ROADMAP



1. Richer degree of semantics, automation
2. Adopt semantic technologies & tools
3. Formalize information related to domain & disciplinary ontology
4. Create interoperability across domains & disciplines
5. Automated reasoning to support decision making
6. Continue to do this across the product lifecycles

Interoperability and Integration Framework (IoIF) using Semantic Web Technologies

IoIF Demos "Full Stack" of models linking Mission and System to Physics-based models



IoIF Workflow Coordinates Simulations and Visualizations

DEVCOM Demos IoIF on Army Network ⇩

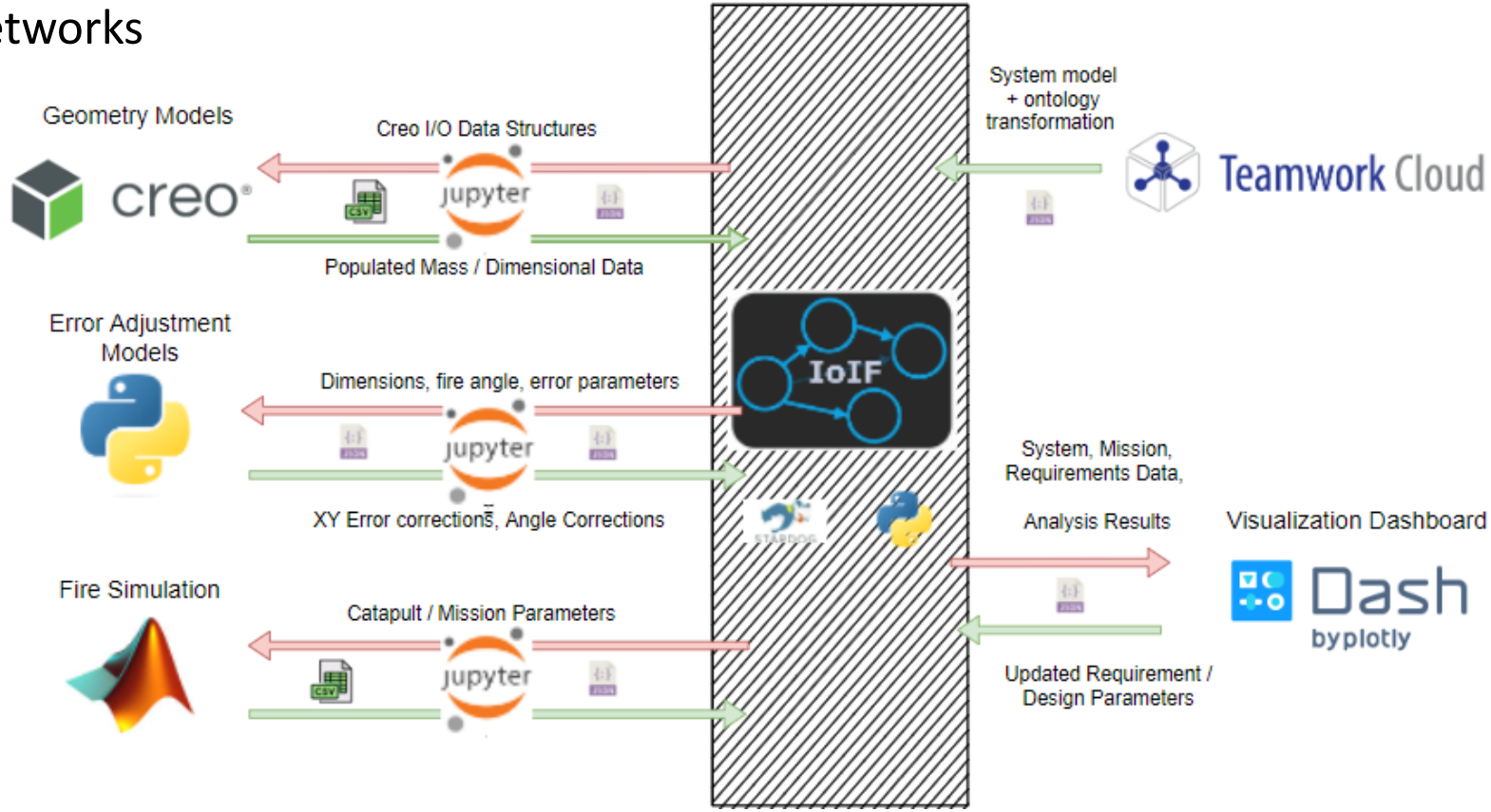
IoIF Workflows coordinate simulations for different roles for different subject matter experts and for different Analysis Types (called instances)

DEVCOM successfully demonstrated to other Army Sponsors an Armaments Case Study and Workflow on Army computers and networks

Role: Geometry Modeler **2**

Role: Operator Aiming **3**

Role: Ballistics Simulation **4**



1 Role: Systems Engineer & IPT Lead

5 Role: Team Trade space Analysis

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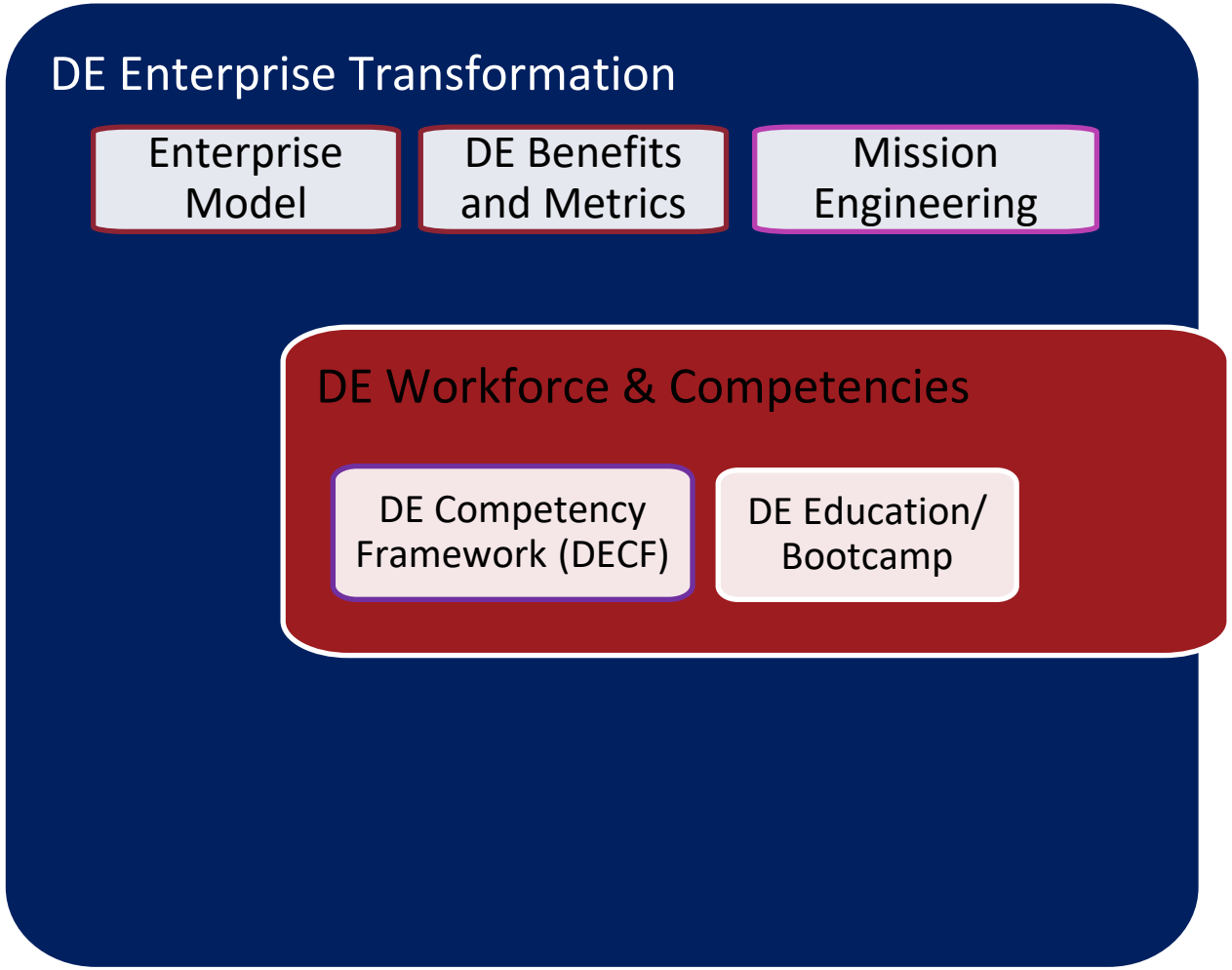
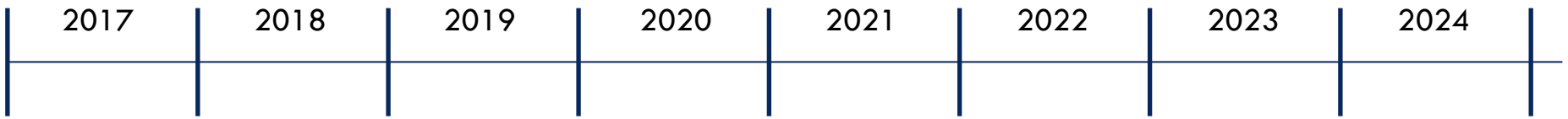


APPLICATIONS OF DE, DIGITAL TRANSFORMATION & WORKFORCE RESEARCH



Global Scan: Systems Engineering research & workforce development needs

DoD Scan: what does gov't acquisition look like after DE has matured?

The SERC MBSE Benchmark Survey: Measuring the benefits of MBSE & DE

First Digital Engineering Measurement Framework

Digital Engineering Competency Framework

Digital Engineering Simulation integrated into DAU training

Looking forward: comprehensive MBSE/DE Pain Points identified, SE Modernization Roadmap

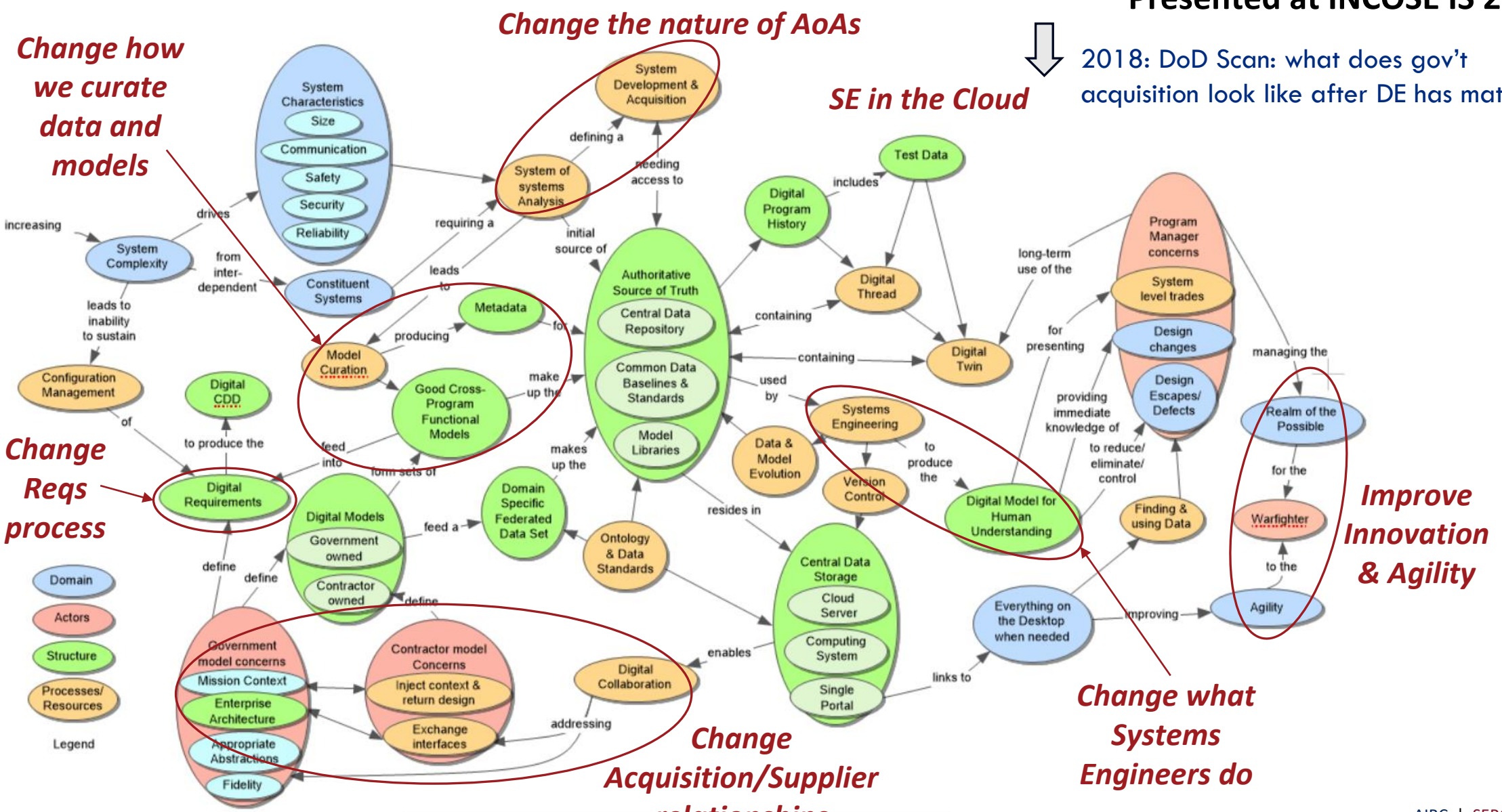
MBSE/DE benefits & measures lead to DE Adoption Model

Agile in Hardware-Intensive Systems Acquisition Center for Enablement

FUTURE DOD DIGITAL INFORMATION EXCHANGE

Presented at INCOSE IS 2017

2018: DoD Scan: what does gov't acquisition look like after DE has matured?



So…How Do We Enable Improved Acquisition with DE?

Looking forward: comprehensive MBSE/DE Pain Points identified, SE Modernization Roadmap

Leverage SW Modernization as an exemplar
– responsive to changing stakeholder needs

Requires **Ontologies** to build common understanding

Systems Thinking

New Mental Models

Agile Mindset → Model-Based → Data Centric → Collaborative

Iterative Approach with **data and models across the lifecycle**

Exemplar Reference implementations will provide templates to help programs get started

The Supra-System
Revised Acquisition Mental-model

- a continuous iterative process
- seamless & efficient transfer of data and models

Here's How…

"Knowledge needs to be liberated from the artifacts"
Dr. Steve Jenkins
JPL/NASA (Retired)

2023: Agile in Hardware-Intensive Systems Acquisition Center for Enablement

What Does an Agile Mindset Mean to SE and DE Modernization?

2023: Agile in Hardware-Intensive Systems Acquisition Center for Enablement

1. Intentionality in Design:

Thoughtful Decomposition and Partitioning

MOSA Precedes Partitioning

Control I/F's and API's

2. Shift Learning Left

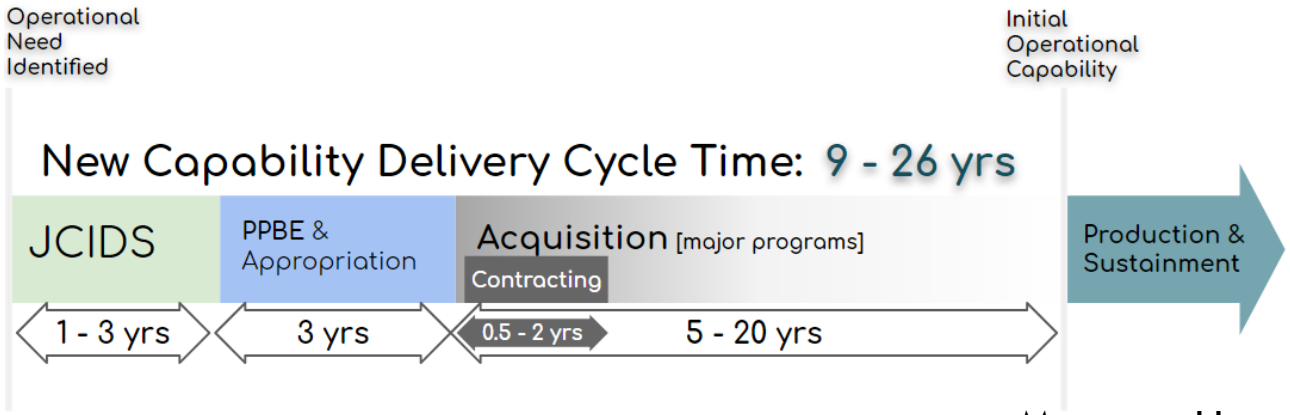
Front-End Investment in Test

Front-End Investment in Infrastructure

3. Avoid "Single-Batch" Mindset

Eliminate Stovepiped Acquisition Stages

Milestone Completion is Buying Down Risk, not Measuring Progress



Refactor Work Steams

Deploy Dedicated IT/Analytics Teams

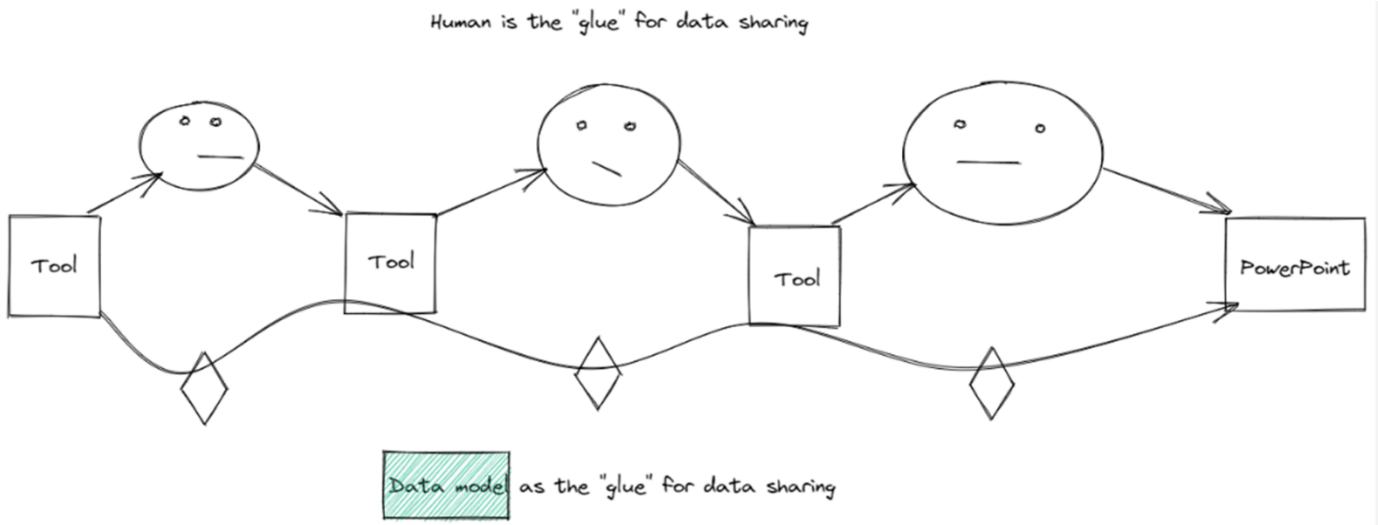
4. Deliver Working Software Frequently

Measure User Satisfaction Like R&M

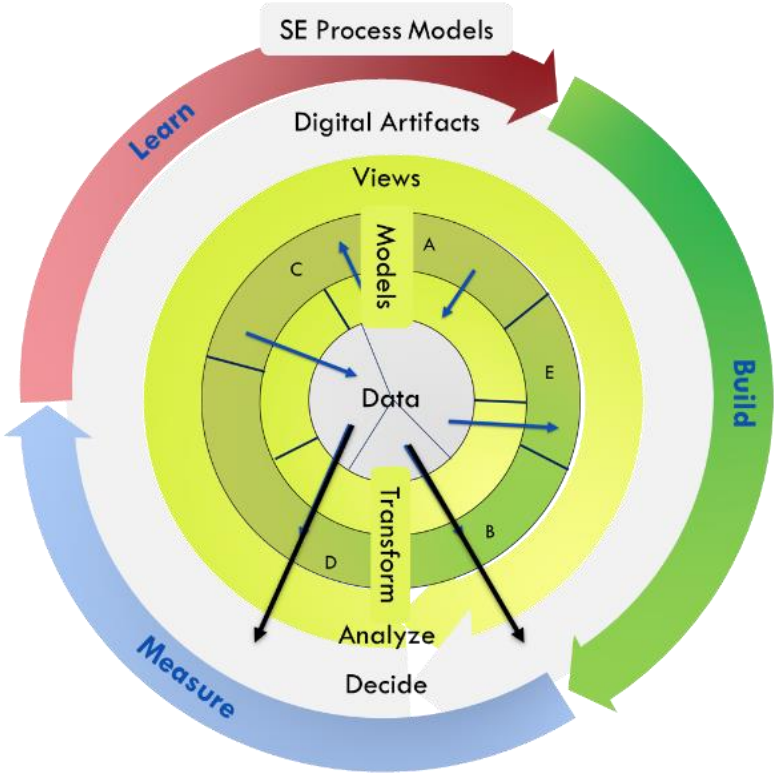
Embed Analytics In the Product

Improve Flow from Warfighter Need To Capability

Two New Mental Models



Digital Artifact - An artifact produced within, or generated from, the engineering ecosystem. These artifacts are generated **through transformation of data and models into views** in order to visualize, communicate, and deliver data, information, and knowledge to stakeholders.



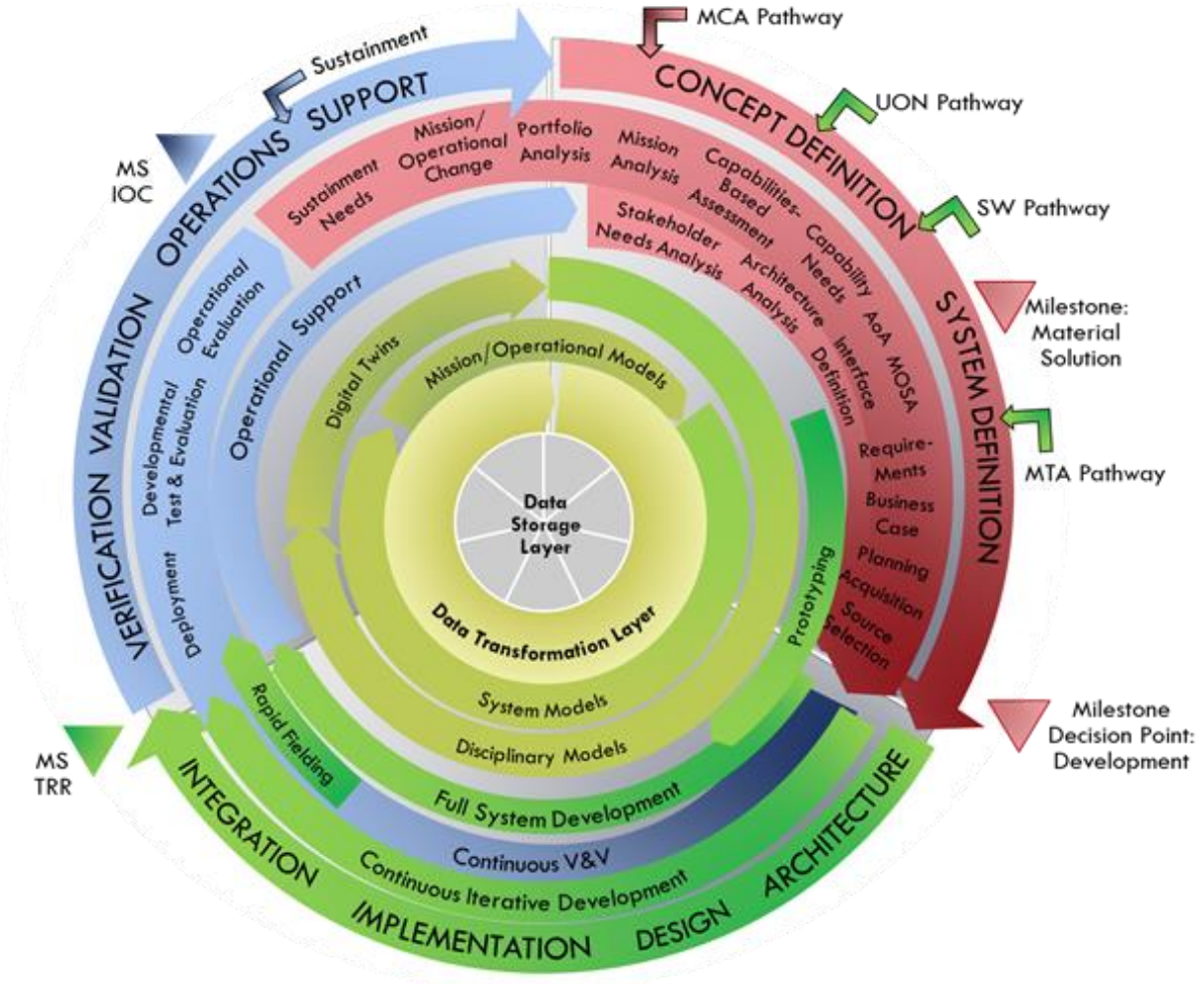
The value of SE Modernization will be realized in more seamless and efficient transfer of data and models from underlying performance drivers through models to decisions, as well as ease of drilling back down from decisions to data.

New SE lifecycle processes must evolve that address shared and authoritatively managed sets of digital data and models associated with the full lifecycle of the system itself, not just a single acquisition program lifecycle.

Notional View: Full SE Modernization Life Cycle

Looking forward: comprehensive MBSE/DE Pain Points identified, SE Modernization Roadmap

- Cyclic nature of modern SE
- Still milestone-based
- SE core principles in every Acq pathway
- Flexible system life cycle entry points:
  Learn-Build-Measure (MCA)
  Build-Measure-Learn (Mid-Tier, SW, UON)
  Measure-Learn-Build (Sustainment)
- Continuous Iterative Development processes (around the circle)
- Continuous Data Management and Transformation processes (at the core)



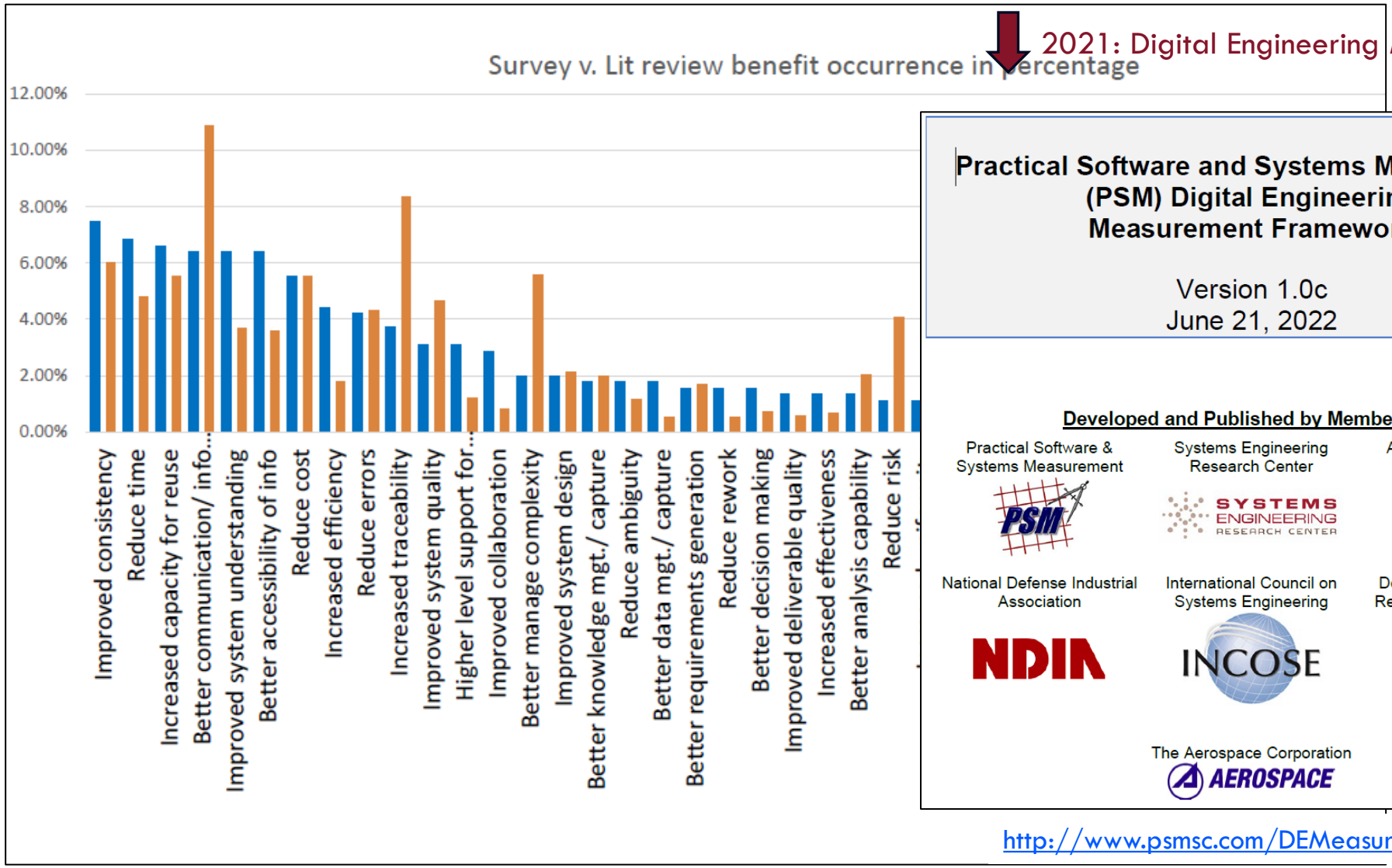
Learn	Needs analysis & Planning
Build	Implementation
Measure	Test, Evaluation, Support
Data & Models	

Areas of Near-term benefit (by Acquisition Function)

1. **Life Cycle Logistics:** ensuring that authoritative data and models and their use are included in the product support strategy and made available to the logistics and supply domain
2. **Engineering and Technical Management:** developing the ASOT and associated Ecosystem
3. **Program Management:** planning and budgeting for data and models, selecting acquisition pathways and defining appropriate DE model-based review processes, staffing the program office with sufficient digitally skilled program office personnel
4. **Test & Evaluation:** V&V requirements and operational assessment with and of models, capturing appropriate digital test artifacts
5. **Business Financial Management/Cost Estimating:** reflecting costs of and potential savings of DE in the complete, executed lifecycle of a system
6. **Contracting:** incorporating data and model exchanges, and digital review processes into the Statement of Work (SOW), defining data and model exchange and delivery requirements
7. **Audit:** ensuring appropriate management of program digital artifacts so curation is possible

TOP-CITED MEASUREMENT AREAS: SURVEY RESULTS

2020: The SERC MBSE Benchmark Survey: Measuring the benefits of MBSE & DE



2021: Digital Engineering Measurement Framework

Practical Software and Systems Measurement (PSM) Digital Engineering Measurement Framework

Version 1.0c
June 21, 2022

Developed and Published by Members of:

Practical Software & Systems Measurement

Systems Engineering Research Center

Aerospace Industries Association

National Defense Industrial Association

International Council on Systems Engineering

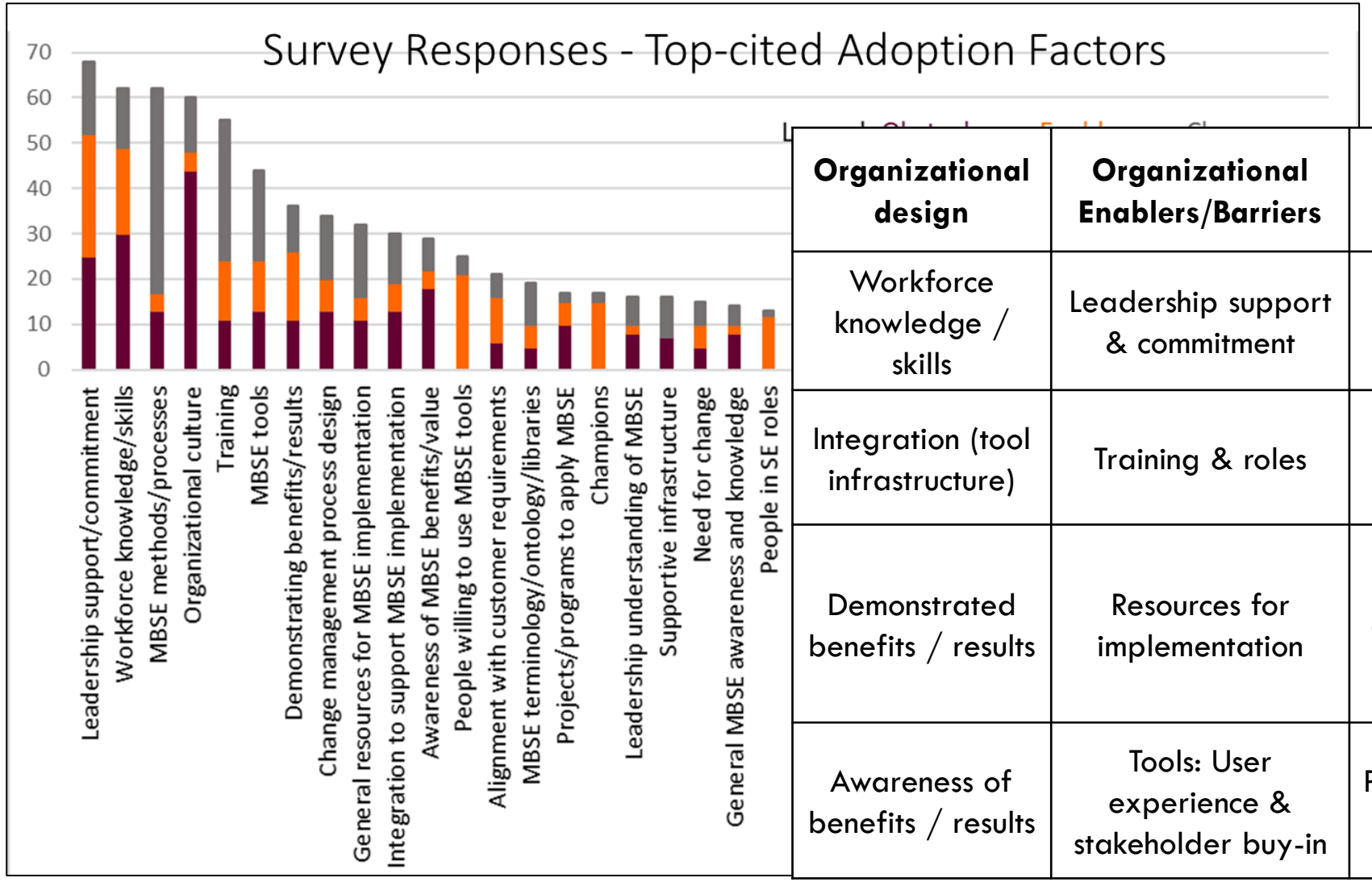
Department of Defense Research & Engineering

The Aerospace Corporation

http://www.psmsc.com/DEMeasurement.asp

Organizational Adoption: Survey Results

2020: The SERC MBSE Benchmark Survey: Measuring the benefits of MBSE & DE

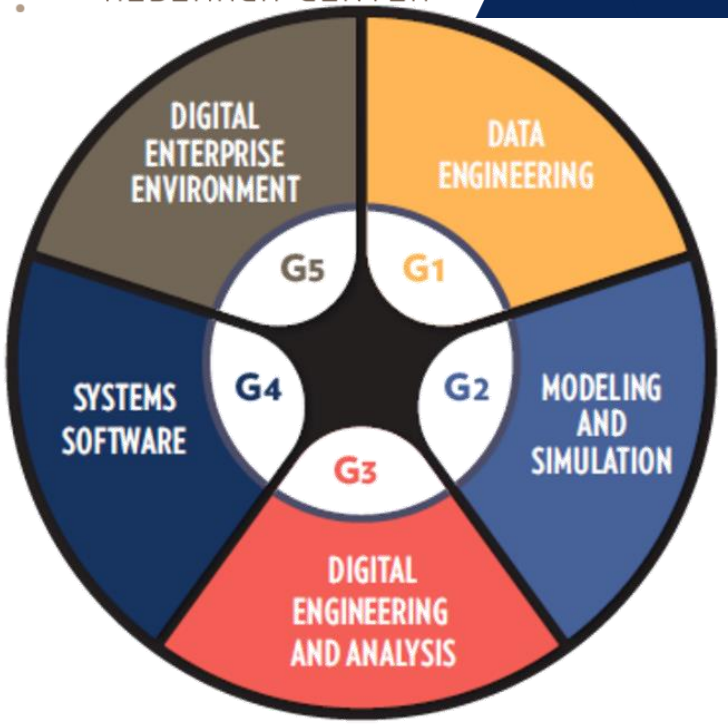


2023: MBSE/DE benefits & measures lead to DE Adoption Model

Organizational design	Organizational Enablers/Barriers	Organizational Change Management
Workforce knowledge / skills	Leadership support & commitment	DE/MBSE methods /process (maturity)
Integration (tool infrastructure)	Training & roles	Change management process design
Demonstrated benefits / results	Resources for implementation	Organizational culture (overcoming resistance)
Awareness of benefits / results	Tools: User experience & stakeholder buy-in	People willing to use the DE/MBSE tools

DIGITAL ENGINEERING COMPETENCY FRAMEWORK (DECF)

2021: Digital Engineering Competency Framework



FOUNDATIONAL DIGITAL COMPETENCIES	
F1	Digital Literacy
F2	Digital Engineering Value Proposition
F3	DoD Policy/Guidance
F4	Coaching and Mentoring
F5	Decision Making
F6	Software Literacy

LEGEND:
C# - Competency Title
F# - Foundational Competency Title
G# - Competency Group
S# - Competency Subgroup

G1 DATA ENGINEERING			
S1	Data Engineering	C1	Data Governance
		C2	Data Management

G2 MODELING AND SIMULATION			
S2	Modeling and Simulation	C3	Modeling
		C4	Simulation
		C5	Artificial Intelligence/Machine Learning
		C6	Data Visualization
		C7	Data Analytics

G3 DIGITAL ENGINEERING AND ANALYSIS			
S3	Digital Systems Engineering	C8	Digital Architecting
		C9	Digital Requirements Modeling
		C10	Digital Validation and Verification
		C11	Model-Based Systems Engineering Processes
S4	Engineering Management	C12	Digital Model-Based Reviews
		C13	Project and Program Management
		C14	Organizational Development
		C15	Digital Engineering Policy and Guidance
		C16	Configuration Management

G4 SYSTEMS SOFTWARE			
S5	Systems Software	C17	Software Construction
		C18	Software Engineering

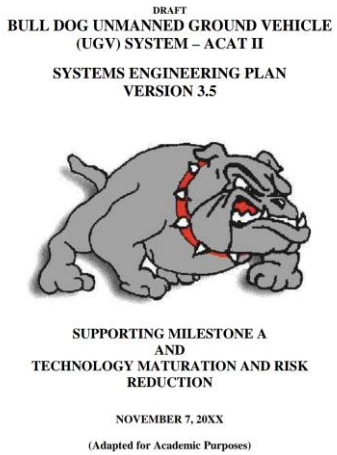
G5 DIGITAL ENTERPRISE ENVIRONMENT			
S6	Digital Enterprise Environment Development	C19	Digital Environment Development
S7	Digital Enterprise Environment Management	C20	Management
		C21	Communications
		C22	Planning
S8	Digital Enterprise Environment Operations and Support	C23	Digital Environment Operations
		C24	Digital Environment Support
S9	Digital Enterprise Environment Security	C25	Digital Environment Security

DAU Credentials: Digital Engineering

2023: Digital Engineering Simulation integrated into DAU training ⇩

6 courses

- SysML
- MBSE
- DE Environment
- DE Technical Processes
- DE Management Processes
- Capstone


DRAFT

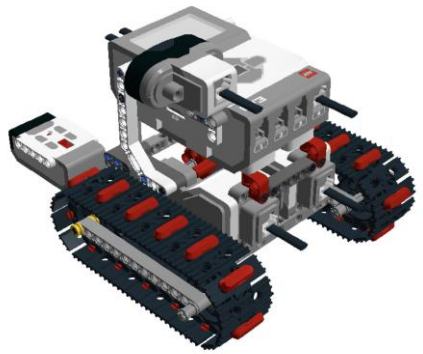
BULL DOG UNMANNED GROUND VEHICLE (UGV) SYSTEM – ACAT II

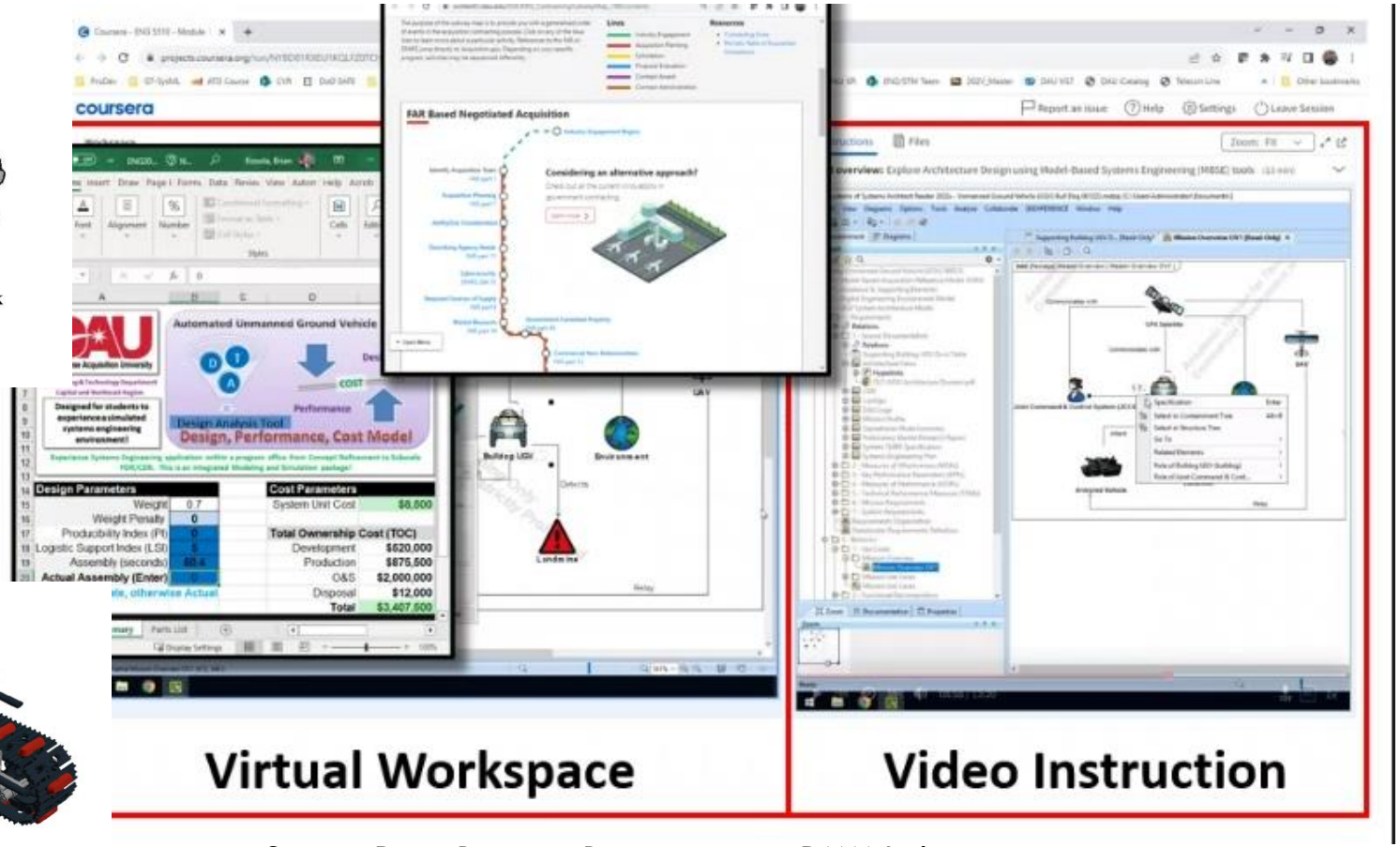
SYSTEMS ENGINEERING PLAN VERSION 3.5

SUPPORTING MILESTONE A AND TECHNOLOGY MATURATION AND RISK REDUCTION

NOVEMBER 7, 20XX

(Adapted for Academic Purposes)

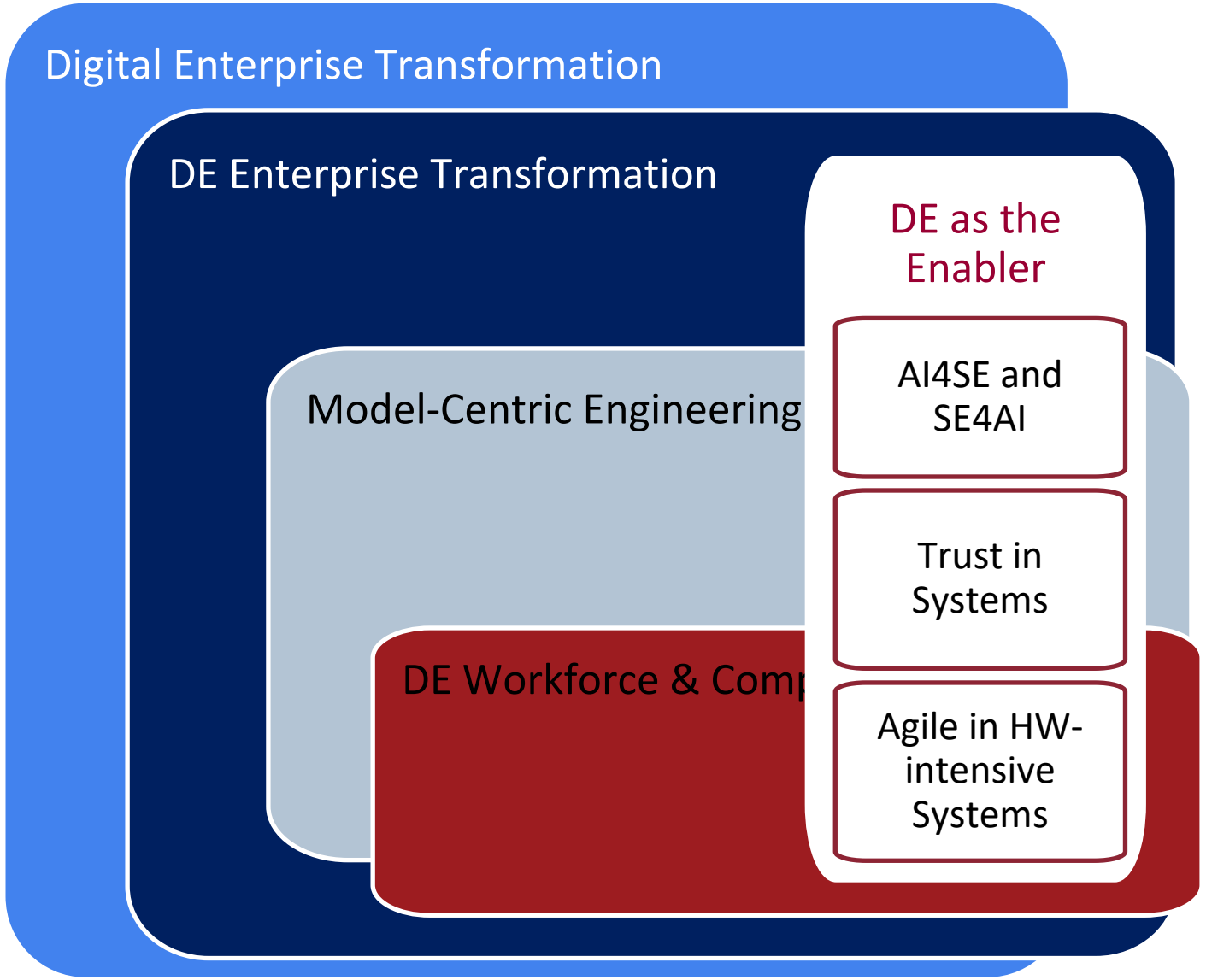




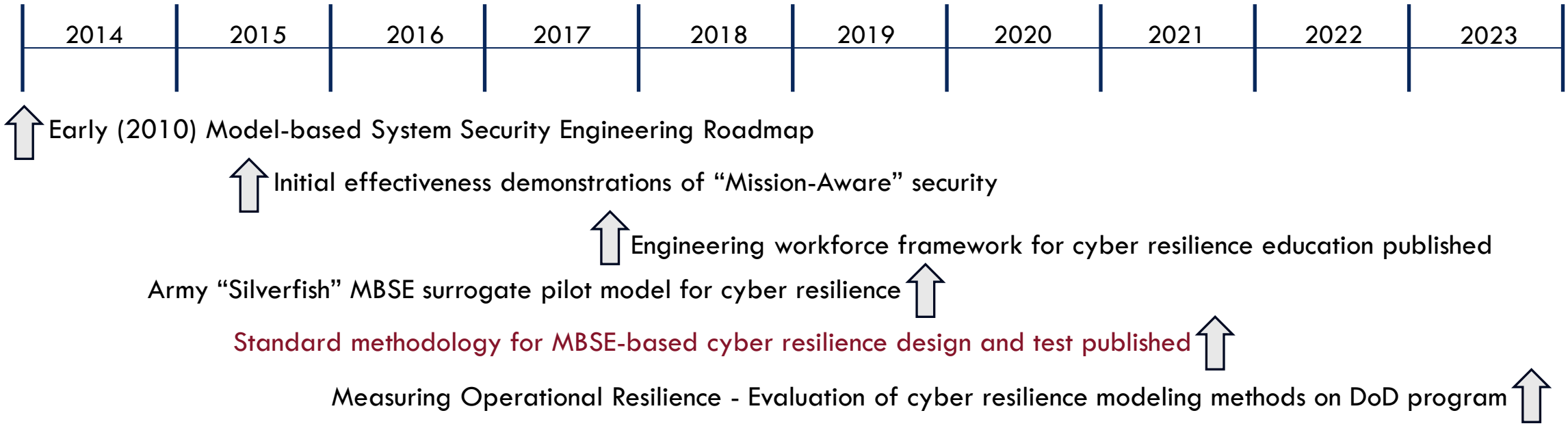
Source: Dave Pearson, Presentation at DMM Industry Association Consortium Kickoff, Nov 2023.

OUTLINE

1. Who we are
2. 10 Years of DE Research, Experimentation, & Demonstration

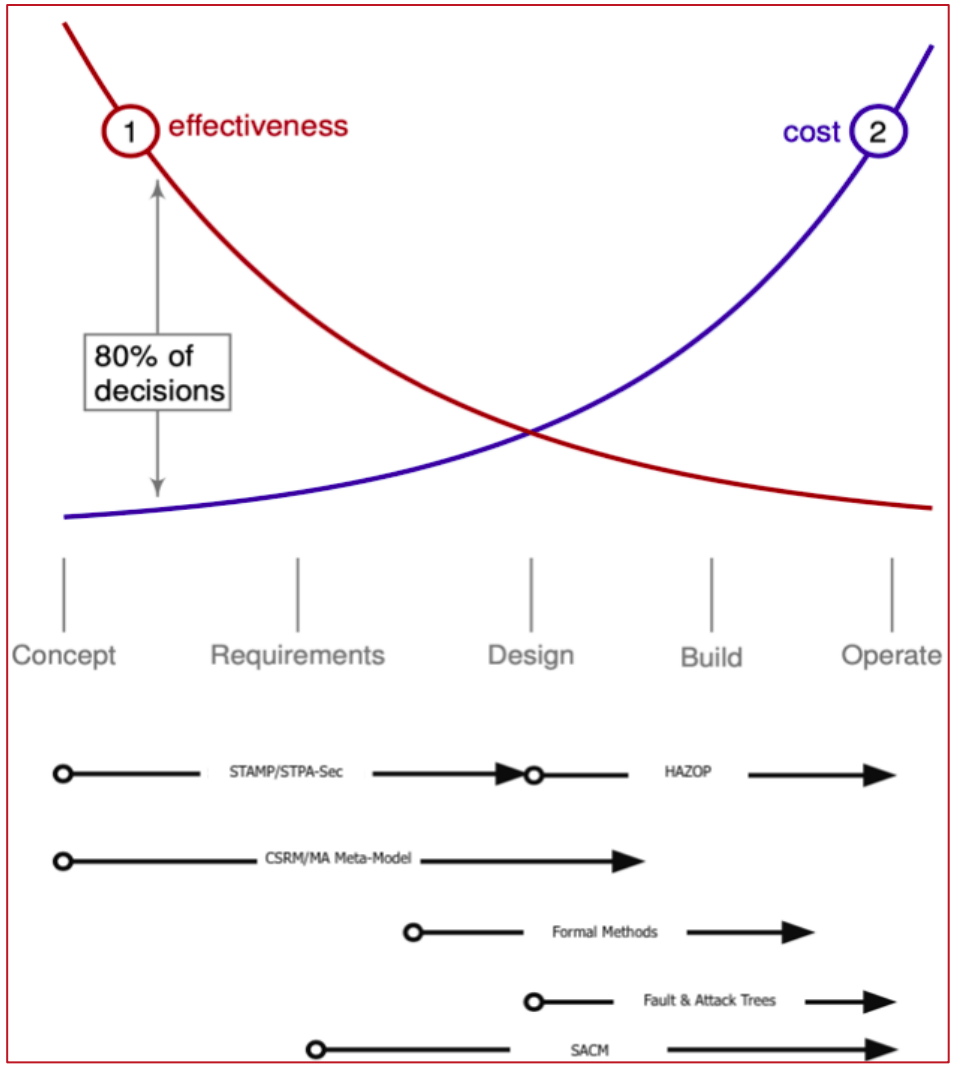


SECURE CYBER-RESILIENT ENGINEERING (SCRE)



Approach: Resilience and Assurance Methodologies – Full System Life Cycle

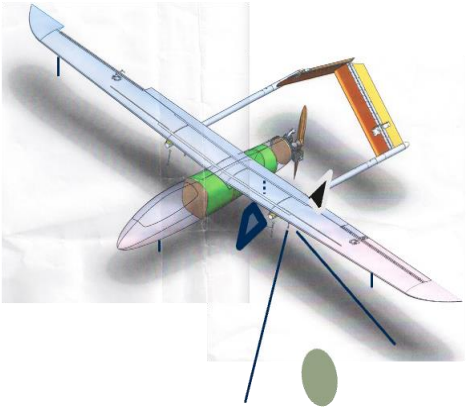
- Need rigorous methods and tools usable in all stages of the SE process
  - From Mission Engineering to Developmental & Operational Test
- Earlier focus on loss causation and resilience
- Later focus on risk management and assurance
- Continuous evaluation of assurance-related quality attributes

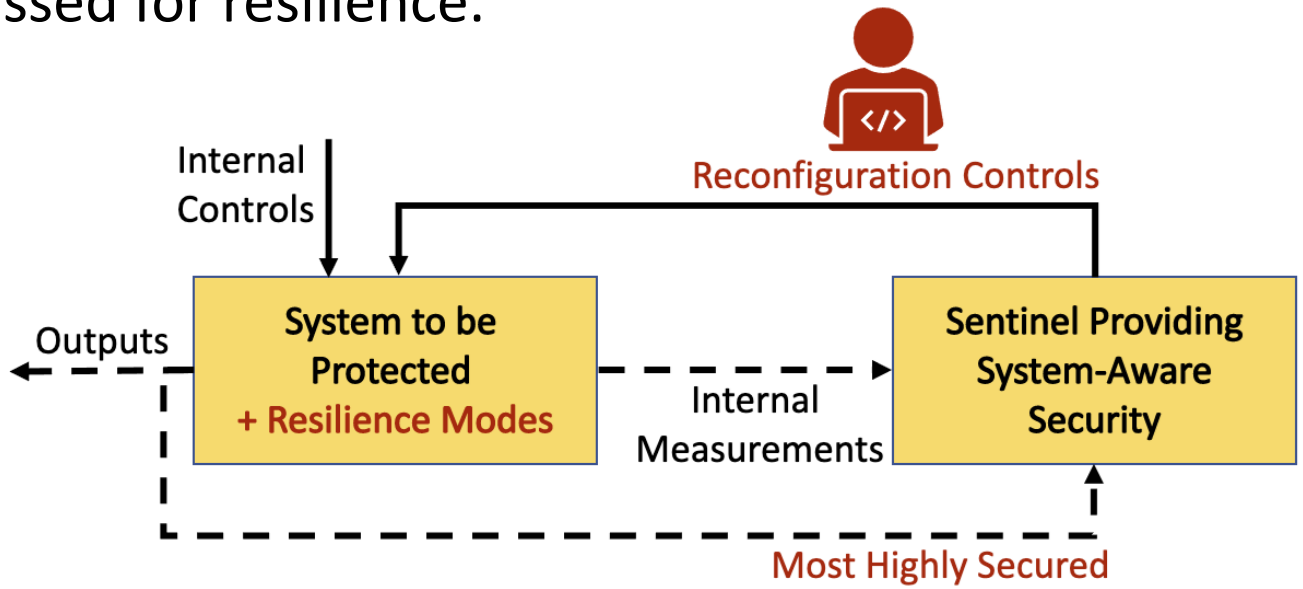


Early (2010) Model-based System Security Engineering Roadmap

SENTINEL-BASED RESILIENCE PATTERN

- A Resilience Mode is a distinct and separate method of operation of a component, device, or system based upon a diverse redundancy or other design pattern.
- A Sentinel is a pattern responsible for monitoring and reconfiguration of a system using available Resilience Modes. The Sentinel functions are expected to be far more secure than the system being addressed for resilience.





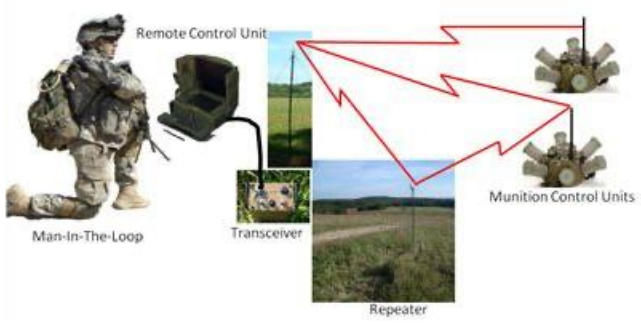
SOME APPLICATIONS OF SENTINELS – EARLY WORK

2015: Initial effectiveness demonstrations of "Mission-Aware" security

Ship Control
(Northrop Grumman)

3D Printers
(NIST)

Human Factors Experiments
(Air Force)

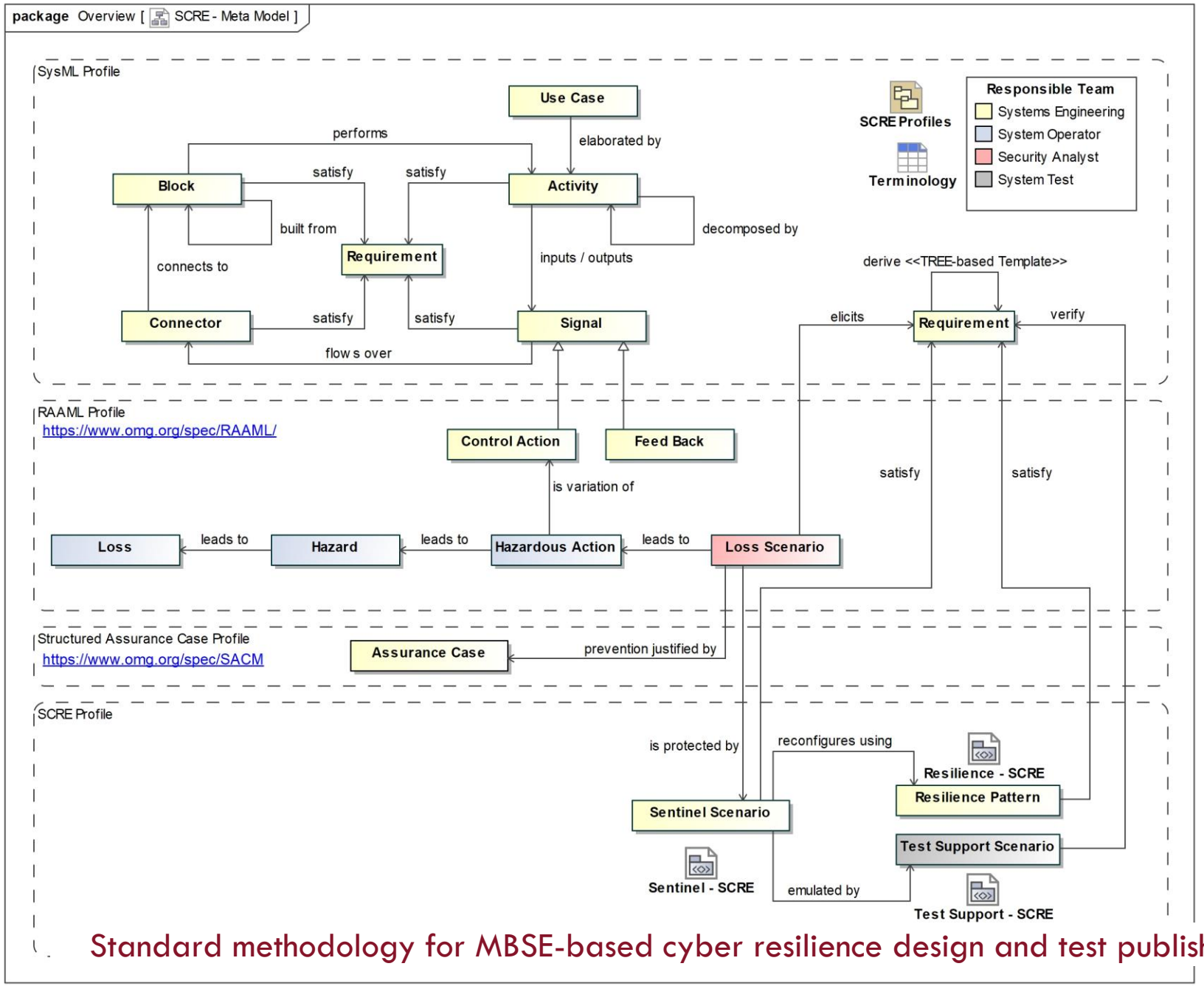


Networked Munitions
(Army)

Cars
(VA State Police)

Industrial Control Sytems
(Mission Secure Inc)

Secure Cyber-Resilient Engineering (SCRE) MBSE Metamodel & Process



SCRE Modeling Tasks: 5-step process

1A - Identify Operational **Use Cases** for *Communication* focus (Problem Framing).

1B – Define Activity Diagrams (**Block, Connector, Signal**) to realize Communication Use Cases

1C – Define Control Structure (**Control Action, Feedback**) to support Communication Use Cases

2 – Perform Hazard Analysis (**Loss, Hazard, Hazardous Action**) for Communication Control Structure

3 – Identify **Loss Scenarios** for Control Structure & Risk Assessment

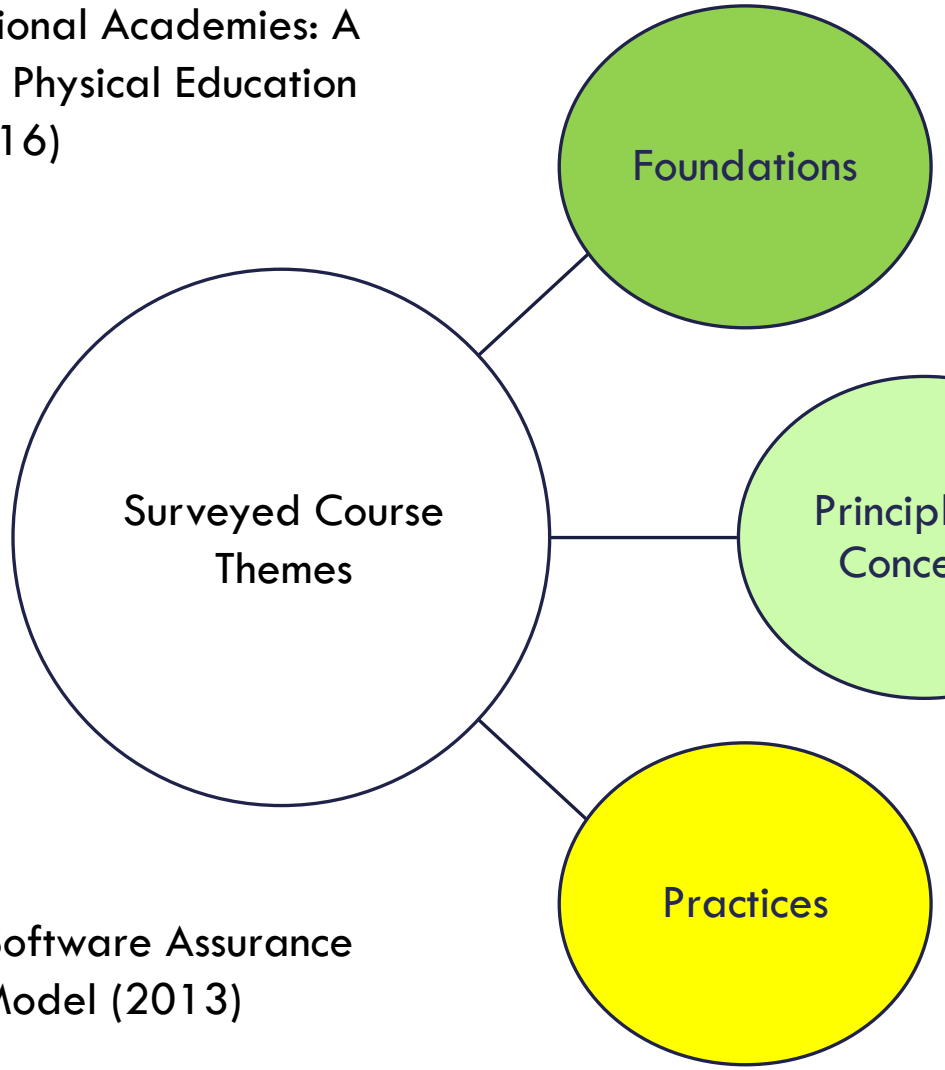
4 – Define Shadow Resilience Architecture (**Sentinel Scenario, Resilience Pattern, SCRE Requirements**) for Loss Scenarios to be 'protected against'. Define **Assurance Cases** for Loss Scenarios to be 'prevented'.

5 – Define Shadow Resilience Test & Evaluation (**Test Support Scenarios**) to verify SCRE Requirements

Standard methodology for MBSE-based cyber resilience design and test published

Derived CPS Security Education Themes

Adapted from: National Academies: A 21st Century Cyber Physical Education (2016)



- Computer Architecture
- Operating Systems
- Discrete Structures
- Data structures
- Algorithms & Programming
- Security & Privacy Concepts

- Computer Security
- Network Security
- Networks & Network Protocols
- Cryptography
- Distributed Systems & Computing
- Cyberphysical Systems

- System, HW & SW Security
- Information Security & Assurance
- Cybersecurity & Society
- Exploitation & Attack Tools
- Cyber Defense
- Systems Engineering

Adapted from: SEI Software Assurance Competency Model (2013)

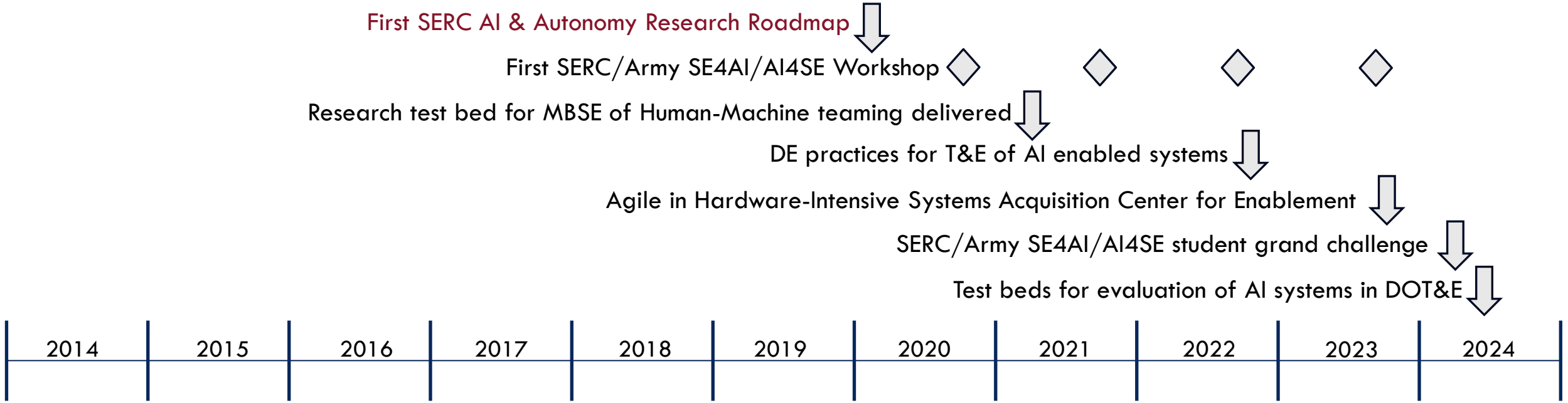
⇧ Engineering workforce framework for cyber resilience education published

SUPPORT FOR DAU COMPETENCIES IN SCRE

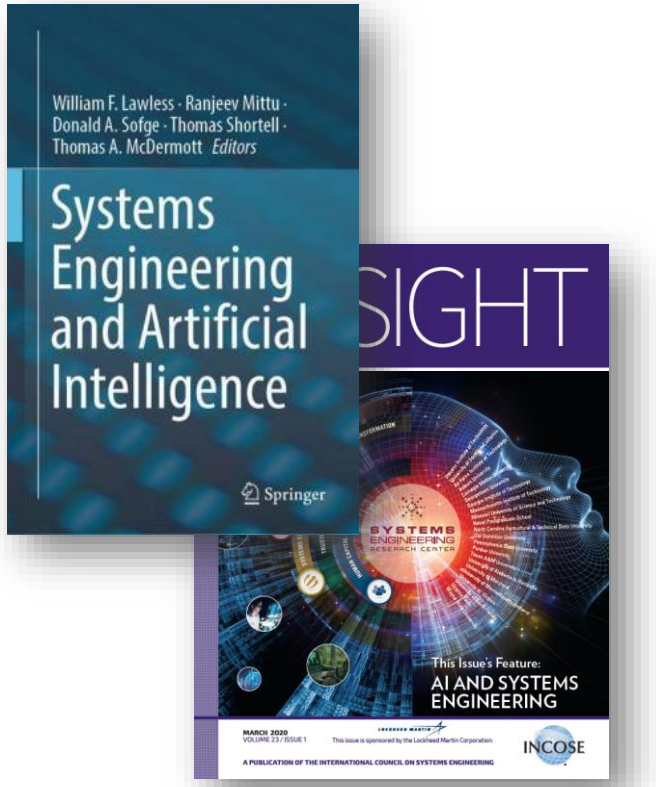
Cyber Resiliency Course Details

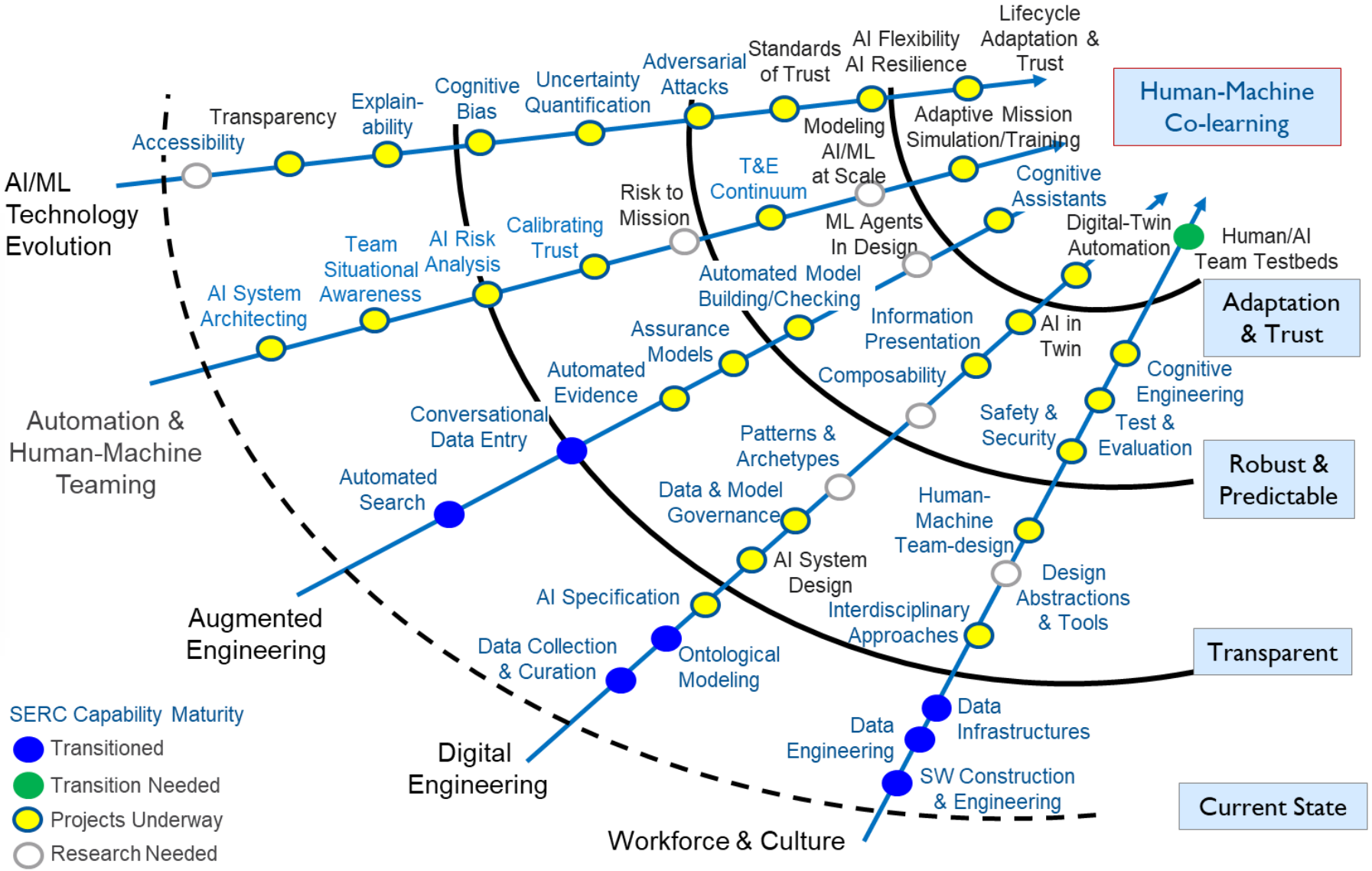
- **Level 1 Cyber Resiliency Foundational Course (1 Day ILT)**
  - The course introduces the concept of Mission Resiliency and Survivability. It provides an approach to addressing Cyber Survivability KPPs (Prevent, Mitigate, Recover) and the Cyber Survivability Attributes (10)
  - Students will dive into the CSRM Methodology and loss based engineering (full process).
  - Students will map the CSAs to applicable security disciplines (ie. AT, CyEng, RMF, SW Assr, HW Assr)
  - Students will analyze applicable Cyber Attacks and Cyber defensive techniques
  - Course may leverage AF SSE Practitioners Course an guidebook, DAU Operational Resiliency Workshop, STPA SEC, MITRE Resiliency Framework, MITRE ATT&CK, MITRE DEFENSE, NIST Cyber Resiliency Techniques, and the MITRE OSD Principles for Trustworthiness, AJs Loss Based Engineering Approach, Cyber Incident Response.
  - Example Scenario of a Loss based system (Silverfish, UAV, Ship, Car, etc..)
- **Level 2 Cyber Resiliency Practitioner Course (2.5 Day ILT)**
  - The course provides training on Modeling Mission Resiliency in a SysML model.
  - STPA SEC, Mission Awareness, Modeling Trust, Model the Principles of Trustworthiness
  - Course may leverage AF Cyber Model, the UAV SERC Mission Aware Model
  - Students will work in a distributed Cameo or Vitech Genesis model of a real system to incorporate Cyber Resiliency techniques and TTPs.
  - Students will present a capstone model of a resilient system

AI4SE, SE4AI


First SERC AI & Autonomy Research Roadmap
First SERC/Army SE4AI/AI4SE Workshop
Research test bed for MBSE of Human-Machine teaming delivered
DE practices for T&E of AI enabled systems
Agile in Hardware-Intensive Systems Acquisition Center for Enablement
SERC/Army SE4AI/AI4SE student grand challenge
Test beds for evaluation of AI systems in DOT&E
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024

2019: SERC AI & AUTONOMY ROADMAP





SE4AI/AI4SE Annual Workshop

- Fourth annual workshop
- 72 Abstracts received, >50 total presenters
- Details for the 2024 annual workshop upcoming

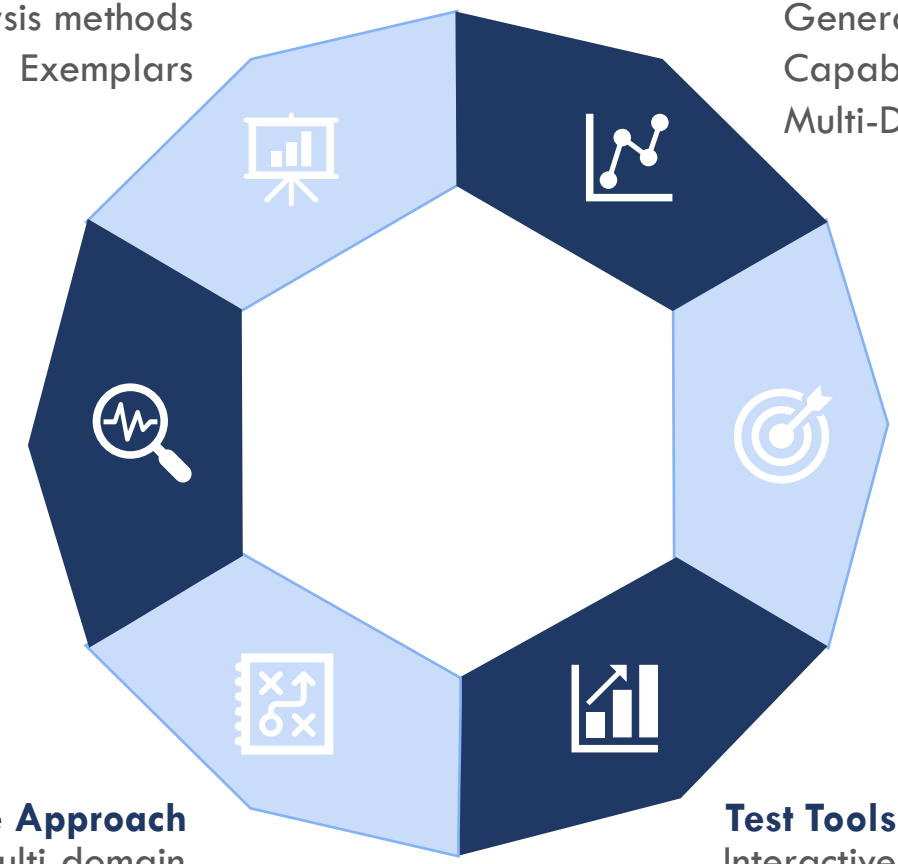
AI T&E Harness

2024: Test beds for evaluation of AI systems in DOT&E

Objectives:

Develop a prototype environment where we can:

1. Test AI model prototypes to accelerate the transition of research and methods into T&E tools
2. Prototype policy, standards, metrics, and risk characterization methods
3. Accelerate education and training of T&E practitioners



Reporting
Sample reports
Analysis methods
Exemplars

Data
Repositories
Generative
Capabilities
Multi-Domain

Education & Training
Learn by doing
Supports walk through of application of T&E program

Model Training
Pretrained models
Pre-loaded training algorithms
Transfer learning

Use Case Approach
Multi-domain
Cross-walk frameworks with application.

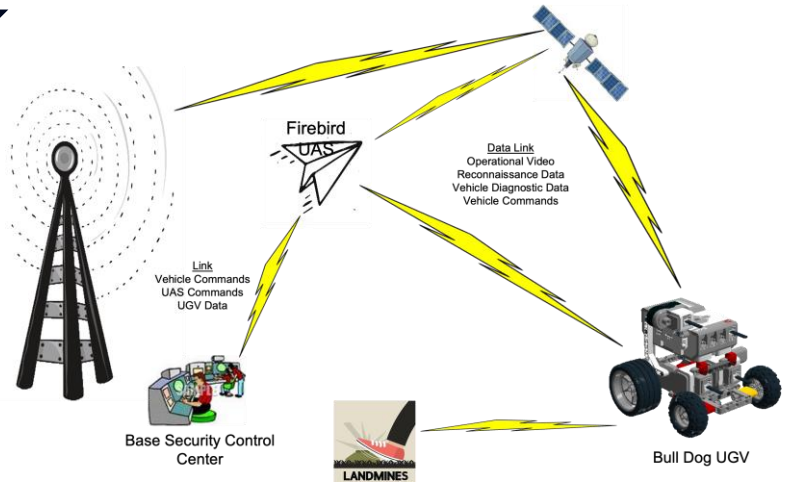
Test Tools & Metrics
Interactive Tools & Dashboards
New operational metrics
Tools for data selection, augmentation

TRUSTED ARTIFICIAL INTELLIGENCE SYSTEMS ENGINEERING CHALLENGE

2024: SERC/Army SE4AI/AI4SE student grand challenge

Teams engage in

- Assured design of AI and autonomy into notional system
- Risk-based monitoring and management of operational use of AI capabilities.



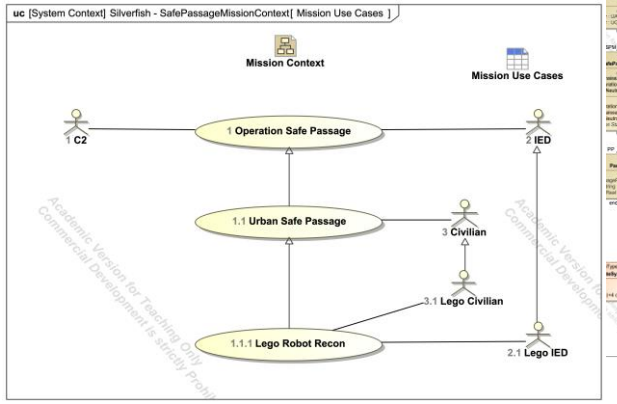
Semester-long Stages:

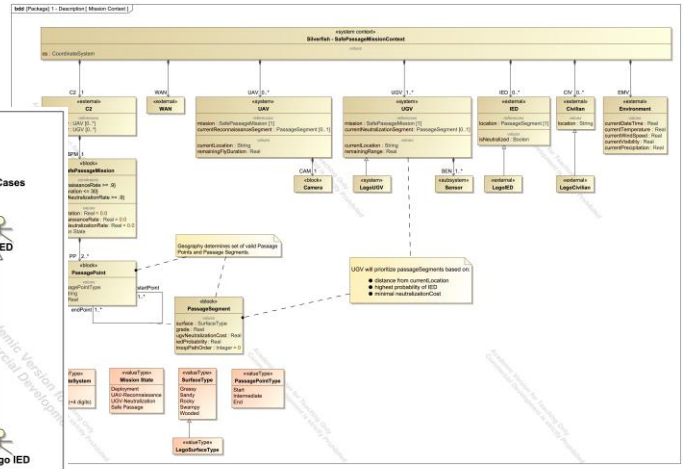
1. Explore performance of AI models over variety of operational scenarios
2. Design of the decision system; human-machine teaming, resilience.
3. Operational simulation of mission scenarios.

Teams judged on quantitative performance & SE approaches used to design and operate the system.

Open to all SERC universities + HBCUs and MSIs

Prizes! Sponsored by DEVCOM





QUESTIONS AND DISCUSSION

SYSTEMS ENGINEERING RESEARCH CENTER

AIRC ACQUISITION INNOVATION RESEARCH CENTER

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