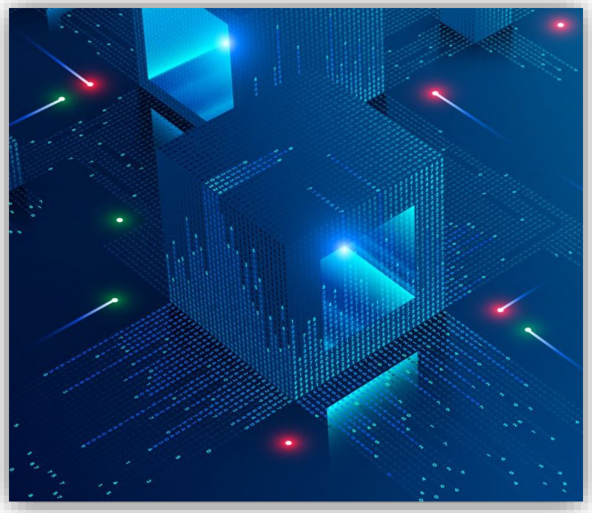
Transition to Digital Engineering: Case Studies and Concepts



Daniel Herber
Assistant Professor of Systems Engineering
daniel.herber@colostate.edu

Ann Batchelor
Assistant Director of Systems Engineering
ann.batchelor@colostate.edu

Outline

- Introduction
- Definitions and Concepts
- Case Studies
- Comments and Tips
- Discussion Questions

Outline

- **Introduction**
- **Definitions and Concepts**
- **Case Studies**
- **Comments and Tips**
- **Discussion Questions**

Motivation

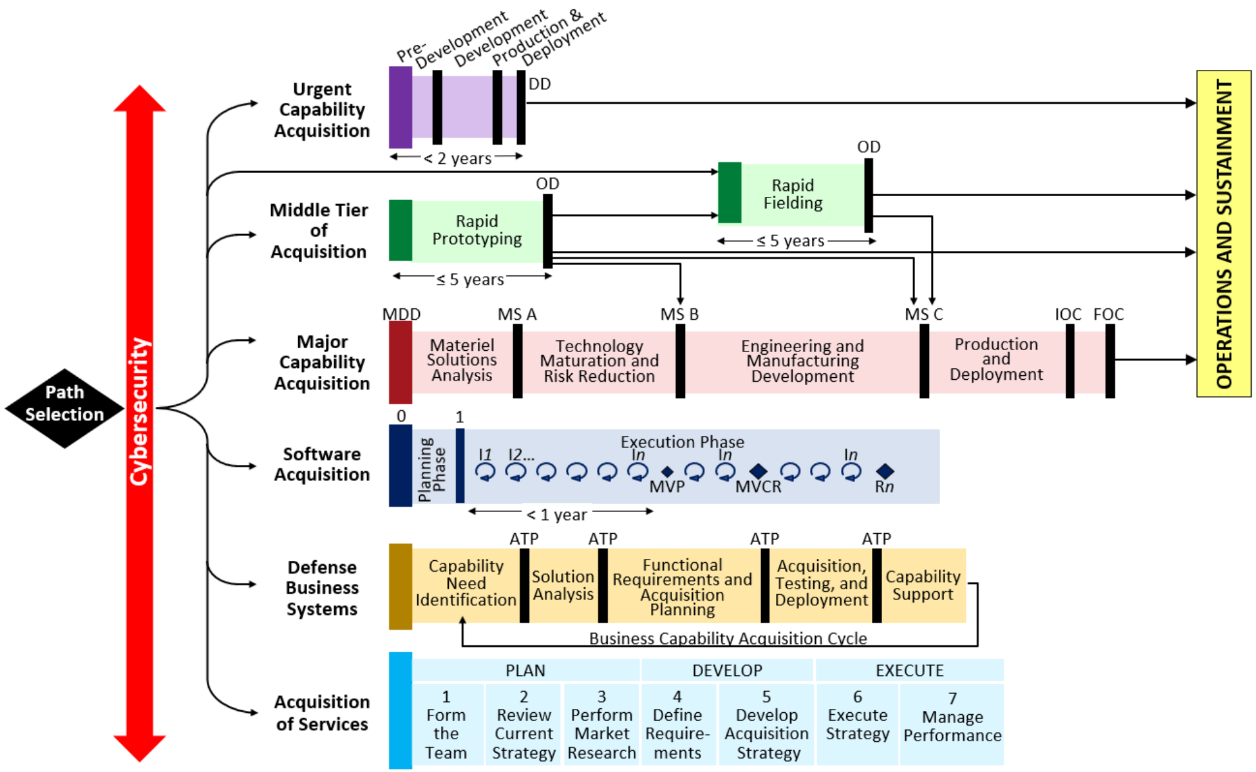
CSU

- Modern systems engineering (SE) evolved in the 1940s through 1960s
- When the first iteration of DoD 5000.01 “The Defense Acquisition System” was published in 1971, little to no software engineering, manufacturing automation, World-Wide-Web, virtualization, MBSE, Industry 4.0, digital twin's, etc.
- Throughout all of this change, the “mainstay” of SE, and associated DoD acquisition guidance, continued to center on physical realization of large-scale monolithic systems intended to persist for many years
- A recent National Defense Magazine article points out the problems with maintaining technological superiority by our cumbersome rules of the US acquisition system and efforts taking place to transform systems engineering
- Furthermore, cost optimization/affordability is increasingly important to maintain competitiveness

The Adaptive Acquisition Framework

CSU

In 2021, the DoD published the latest 5000 series guidance, "The Adaptive Acquisition Framework" (AAF), which recognizes new development and acquisition pathways



Does SE Need to be Modernized, and What Might That Look Like?
https://sercuarc.org/systems-engineering-modernization/

Trends in Lines of Code

CSU

Various aspects of system development are becoming more complex

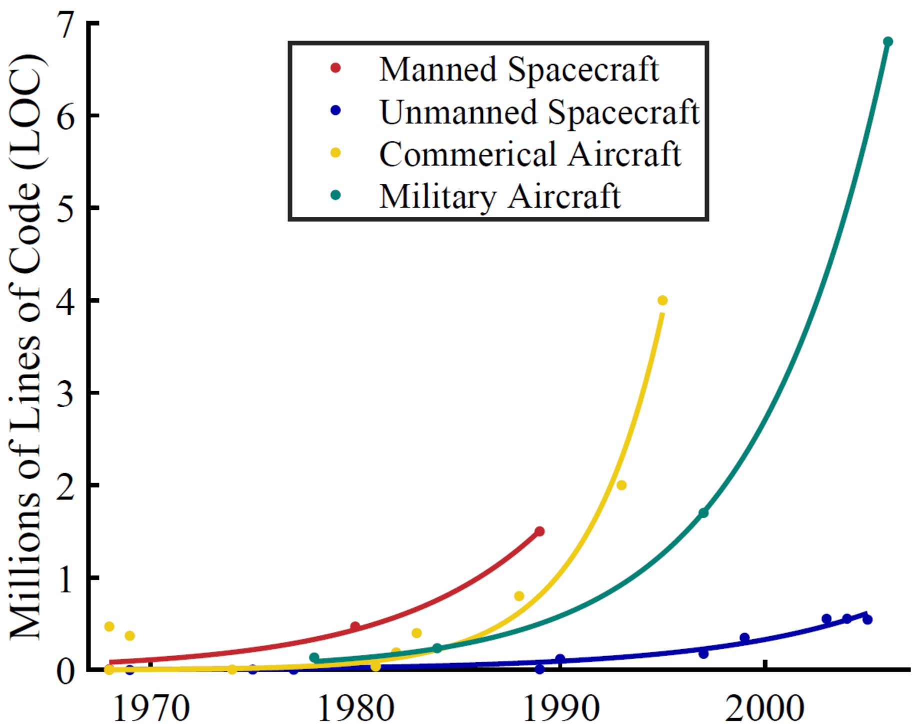


Figure 1: Historical trends in lines of code in various domains (data from (Dvorak 2009; Potocki de Montalk 1993; Hagen and Sorenson 2013; Schenker, T. Smith, and Nichols 2022)).

Full SE Modernization Lifecycle

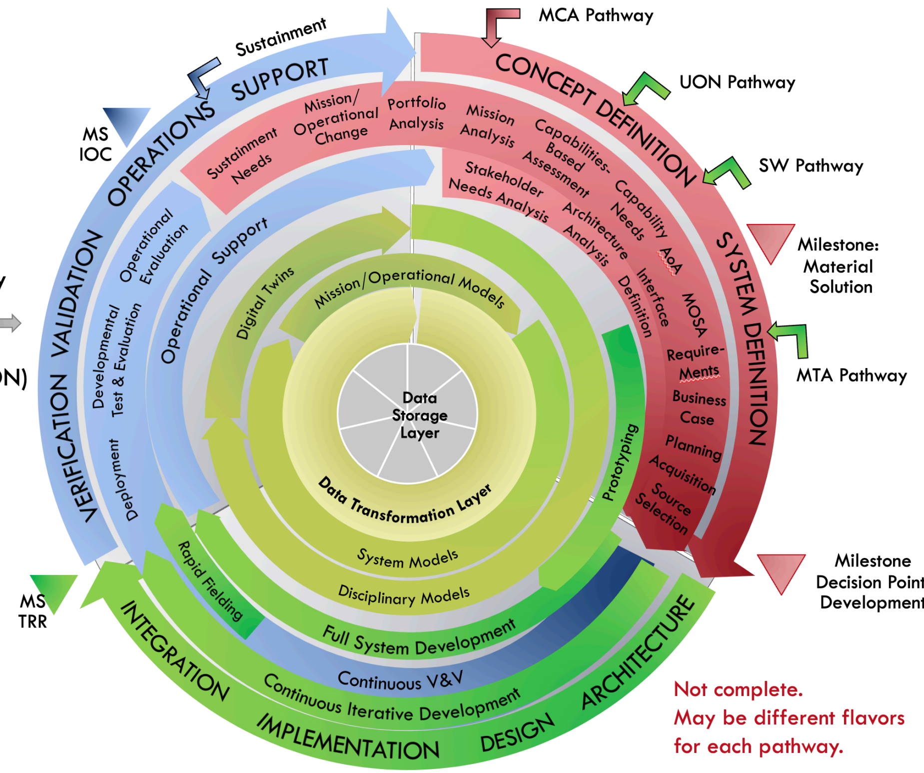
CSU

SE processes are being modernized to be more agile, data/model-centric to meet the needs of modern era

NOTIONAL VIEW: FULL SE MODERNIZATION LIFE CYCLE

- 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



Does SE Need to be Modernized, and What Might That Look Like?
https://sercuarc.org/systems-engineering-modernization/

Outline

- Introduction
- **Definitions and Concepts**
  - o Digital Engineering
  - o Digital Twin
  - o Digital Thread
  - o Model-based Systems Engineering
  - o Digital Transformation
- Case Studies
- Comments and Tips
- Discussion Questions

Definitions – Digital Engineering

CSU

- ***Digital Engineering*** **is defined as:**
  - o "An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support lifecycle activities from concept through disposal."
- **Effective *digital engineering* aims to:**
  - o Formalize the development, integration, and use of models to inform enterprise and program decision making
  - o Provide an enduring, authoritative source of truth so that stakeholders have the current, authoritative, and consistent information for use over the lifecycle
  - o Incorporate technological innovation to improve the engineering practice beyond traditional model-based approaches with rapid implementation of innovations
  - o Establish a supporting infrastructure and environments to perform activities, collaborate, and communicate across stakeholders
  - o Transform the culture and workforce to adopt and support digital engineering across the lifecycle

DoD Digital Engineering Strategy June 2018
https://man.fas.org/eprint/digeng-2018.pdf

Definitions – Digital Twin

CSU

- ***A** Digital Twin* **is defined as:**
  - o "A set of virtual information constructs that mimics the structure, context and behavior of an individual/unique physical asset, or a group of physical assets, is dynamically updated with data from its physical twin throughout its life cycle and informs decisions that realize value."
  - o "A Digital Twin is a virtual representation of a connected physical asset."
- **The essential elements of a *digital twin* are a virtual representation (*model*), a physical realization (*asset*), and a transfer of data/information (*connected*) between the two**
- **A *digital twin* encompasses the entire product lifecycle of a physical asset:**
  - o The design and engineering phase ("As Designed")
  - o The manufacturing phase ("As Built")
  - o The operational/sustainment phase ("As Used" and "As Maintained")
- **A virtual representation (model) enables rapid exploration/understanding**

Digital Twin: Definition & Value
https://www.aia-aerospace.org/publications/digital-twin-definition-value-an-aiaa-and-aia-position-paper/

Definitions – Digital Thread

CSU

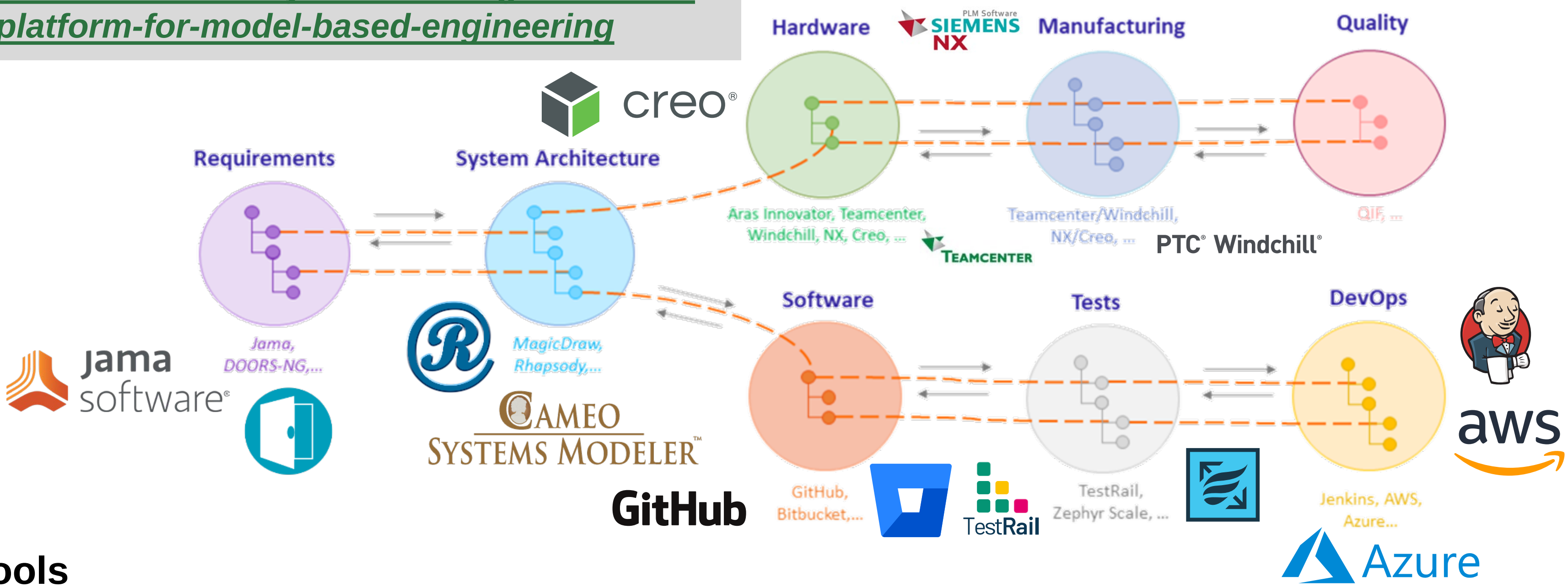
- ***A*** ***Digital Thread*** **is defined as:**
  - o "A data-driven architecture that links together information generated from across the product lifecycle and is envisioned to be the primary or authoritative data and communication platform for a company's products at any instance of time."
- **This communication framework connects traditionally siloed elements providing full traceability and connectivity from concept through design, manufacturing, and service**
- **End-to-end process visibility is required for better cross-team collaboration and the early detection of anomalies to reduce these risks**
- **The *digital thread* is a key enabler for realizing a *digital twin***
- **This generally is not understood to mean one common software platform**
  - o Rather the "best-of-breed" tools and data are coupled together through digital threads

What is the Definition of a Digital Thread?
https://www.jamasoftware.com/blog/what-is-the-definition-of-a-digital-thread/

Digital Threads with Tools and Interoperability

CSU

Modified from https://intercax.com/2021/07/20/new-video-introduction-to-syndeia-the-digital-thread-platform-for-model-based-engineering



- **Tools**
  - There are many different tools for specific aspects of the digital engineering needs
  - Often requires training and the right mindset for effective use in a DE environment
- **Interoperability**
  - Many large tool vendors are building interoperability between other tools (enabling digital threads between different kinds of data and tools)
  - There are also formats/standards (SysML, ReqIF, Modelica, FMI, XML schemas, CSV, Open Services for Lifecycle Collaboration (OSLC), etc.) that facilitate more general interoperability between and inside of the different layers

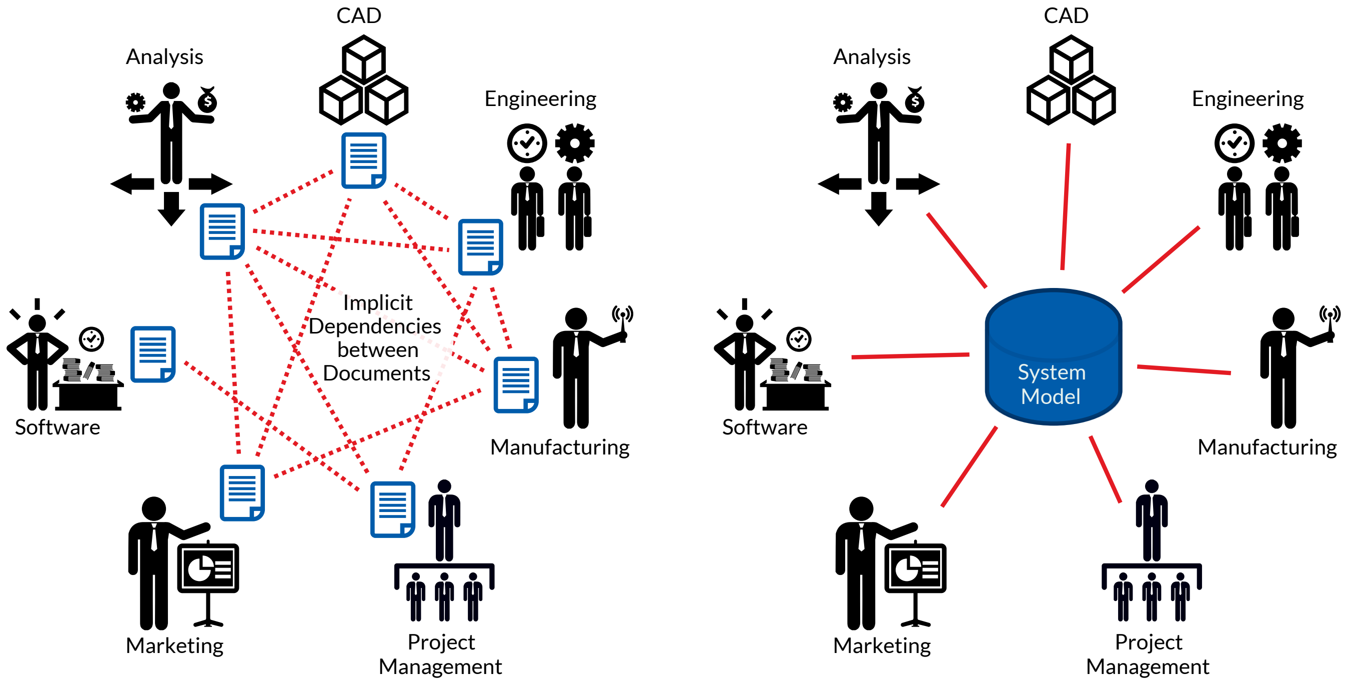
Definitions – Model-Based Systems Engineering

CSU

- ***Model-based Systems Engineering* is defined as:**
    - o “formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.”
- **MBSE puts models at the center of system design and management rather than separate documents and pieces of data**
- **Can provide a critical single-source-of-truth, a single point of access and definition for data/system understanding**
- **MBSE (or the model created with it) is often seen as a critical component of an effective digital engineering strategy and a piece of both digital threads and digital twins**

SYSTEMS ENGINEERING VISION 2020
http://www.ccose.org/media/upload/SEVision2020_20071003_v2_03.pdf

Document-centric SE vs. MBSE



(a) Traditional document-centric SE approach

(b) Model-based SE approach

Definitions – Digital Transformation

- ***A Digital Transformation* is defined as:**
  - “Digital transformation is the integration of digital technology into all areas of a business, fundamentally changing how you operate and deliver value to customers.”
- **Therefore, digital engineering might be seen as a part of greater organizational digital transformation efforts**
- **This sometimes means walking away from long-standing business processes that companies were built upon in favor of relatively new practices that are still being defined**

What is digital transformation?
https://enterprisersproject.com/what-is-digital-transformation

Outline

- Introduction
- Definitions and Concepts
- **Case Studies**
    - o Boeing T-7A Red Hawk
    - o Submarine Warfare Federated Tactical Systems (SWFTS)
- Comments and Tips
- Discussion Questions

Case Study – Boeing T-7A Red Hawk (1)

- In September 2018, Boeing received the USAF contract worth $9.2 billion to build 351 advanced trainer aircraft and 46 associated ground-based training simulators
- T-7A Red Hawk is a supersonic 47 ft long plane, was purpose-built to include provisions for growth, improve supportability, and innovate a maintenance-friendly design

T-7A Red Hawk
https://www.boeing.com/defense/t-7a/

Case Study – Boeing T-7A Red Hawk (2)

CSU

- **This build "broke the norm" by incorporating:**
  - Digital engineering processes
  - Agile software development
  - An open architecture mission system to enable more rapid, affordable future aircraft development
  - Fully designed using 3D model-based definition and data management systems
  - Modular design
  - Advanced fighter-like performance
- **Resulted in concept to first flight in 36 months!**
- **According to Boeing, compared to traditional aircraft development programs, T-7A experienced:**
  - 75% increase improvement in first-time engineering quality
  - 80% reduction in assembly hours
  - 50% reduction in software development and verification time

Case Study – MBSE in SWFTS (1)

CSU

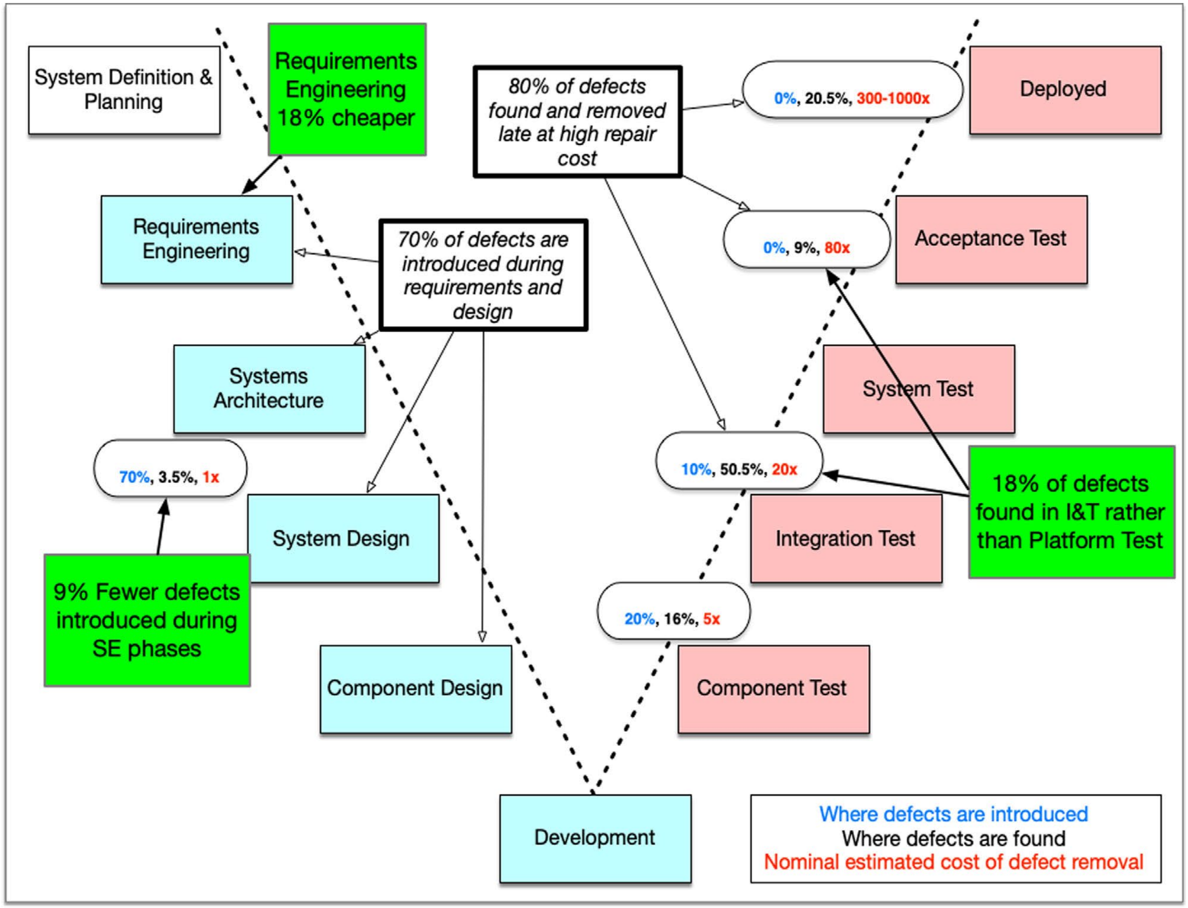
- The Submarine Warfare Federated Tactical Systems (SWFTS) is a rapidly evolving combat system of systems (SoS) product family
- Managing the annual baseline updates requires processing thousands of baseline change requests, then coordinating and verifying their implementation
- The complexity of this effort, which involves well over ten million source-lines-of-code (SLOC) as well as Commercial-Off-the-Shelf (COTS) and military-unique hardware, is compounded by being deployed in ten variants

MBSE delivers significant return on investment in evolutionary development of complex SoS
https://doi.org/10.1002/sys.21592

Case Study – MBSE in SWFTS (2)

CSU

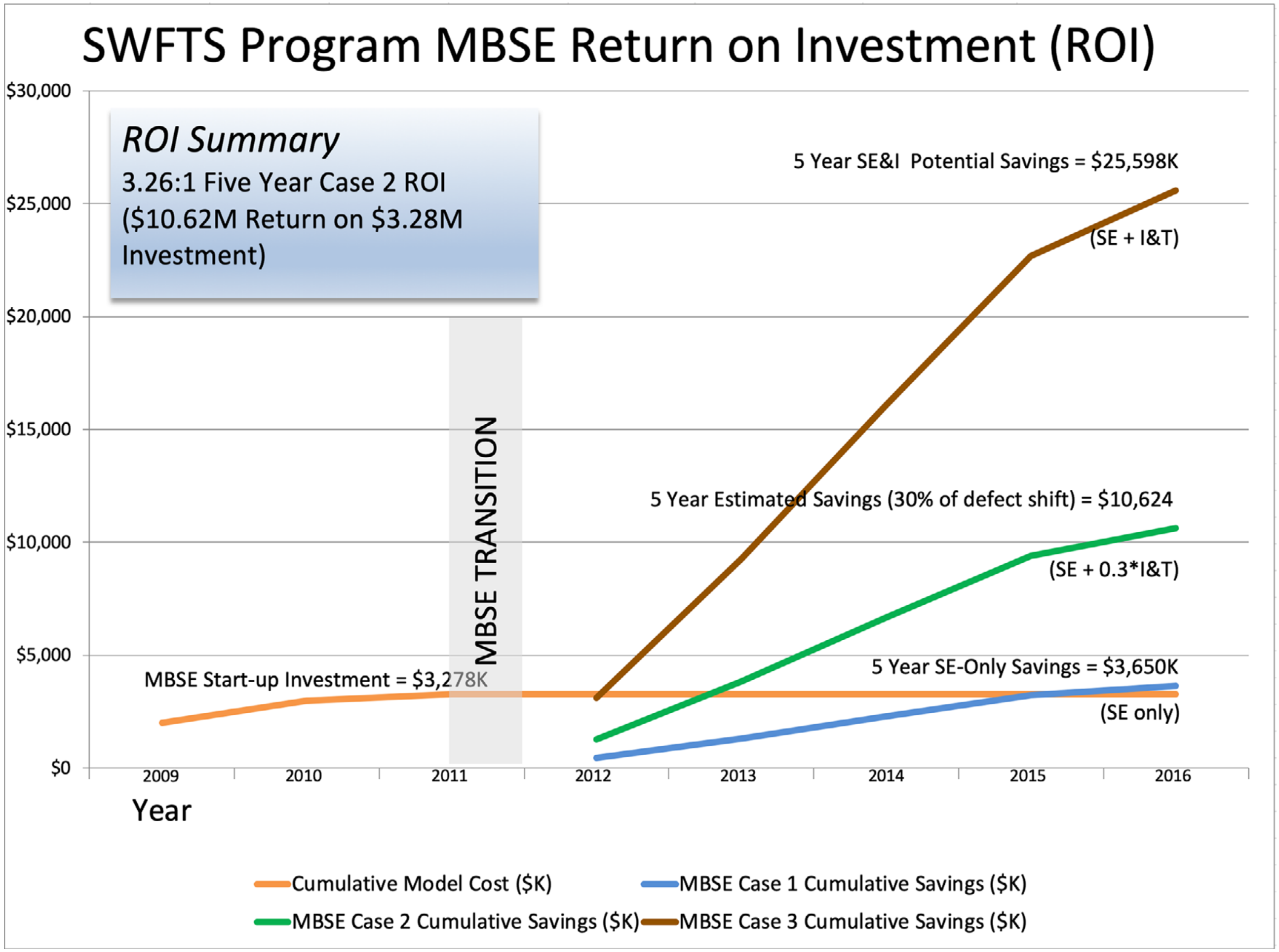
MBSE rather than a document-centric approach resulted in lower requirements development costs and fewer defects that were also identified earlier



Case Study – MBSE in SWFTS (3)

CSU

A more effective, more model-centric digital engineering approach was shown to provide a positive return on investment (ROI)



Case Study – Capture and Orient Module

- Recent work by CSU investigated MBSE vs. non-MBSE for an orbiting sample Capture and Orient Module (COM) architecture for potential Mars Sample Return (MSR)
- In the MBSE approach, 49% of total knowledge processing was automate

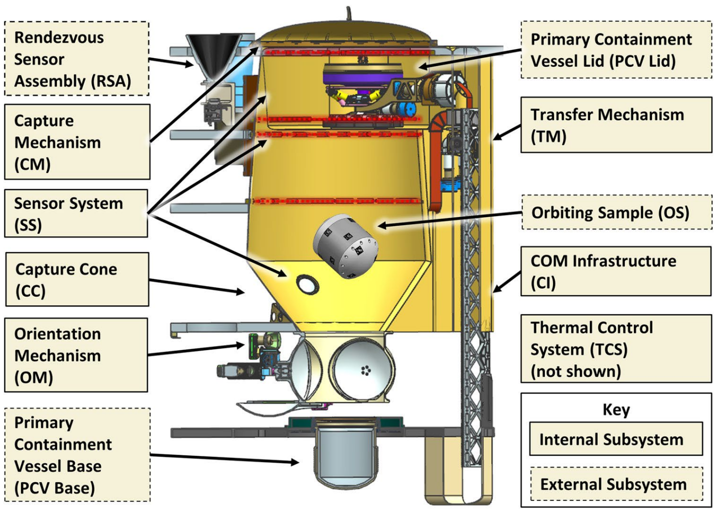


TABLE 10 Comparison of automation of knowledge processing for MBSE and non-MBSE approaches

		Automation		
		Automated	Manual	Total
Approach	Non-MBSE	0	5758	**5758**
	MBSE	2824	2934	**5758**

Comparative analysis of model-based and traditional systems engineering approaches for simulating a robotic space system architecture through automatic knowledge processing
https://doi.org/10.1002/sys.21619

Outline

CSU

- Introduction
- Definitions and Concepts
- Case Studies
- **Comments and Tips**
  - o Game changers, expected benefits, and parting thoughts
- Discussion Questions

Five Game Changers of Digital Engineering

CSU

Fundamental engineering principles prevail

- Going digital doesn't mean that the fundamental principles of engineering are out of date, they are just enhanced by technology

Rapid digital evolution

- Processes are continuously evolving
- The current technologies today may soon become outdated, replaced by faster and more efficient tools

Unlocking data is key

- Data capture and manipulation is essential and requires a digitally savvy engineer

Collaborative practice is reborn

- Collaborative real-time processes of co-design and review are emerging

Improved optioneering

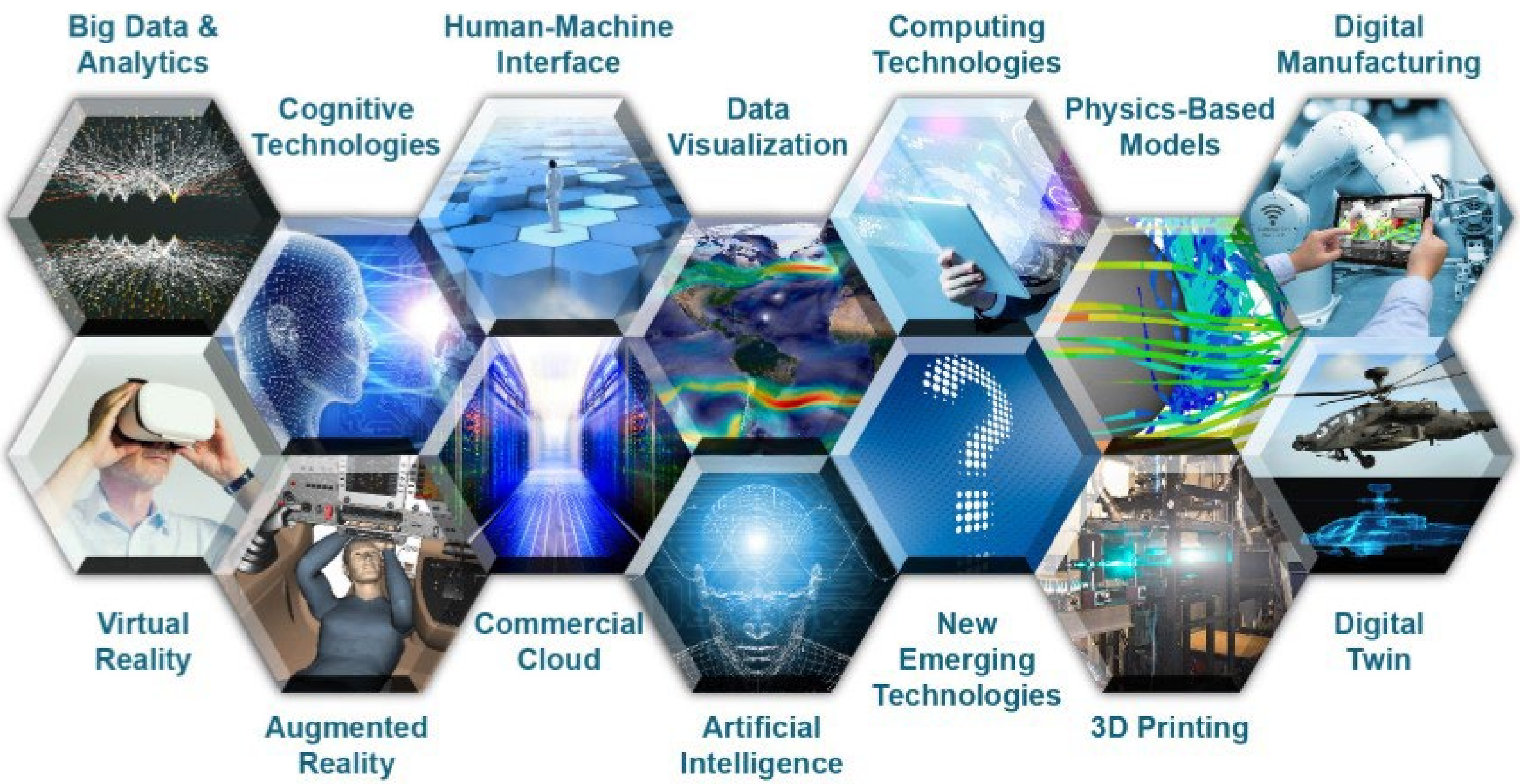
- Enabling new, more efficient ways to generate multiple design options and evaluate them

What is digital engineering?
https://www.aurecongroup.com/expertise/digital-engineering-and-advisory/defining-digital-engineering

Enabling Technologies

CSU

Variety of technology innovations that will enable digitally-connected enterprise and drive innovation to transform the practice of engineering



DoD Digital Engineering Strategy June 2018
https://man.fas.org/eprint/digeng-2018.pdf

Case What Does This Mean? – Big Changes

- The traditional "V" is still in use but repetitive in shorter time frames (Rolling wave, Agile) – increased flexibility
- Transition from document to digital project artifacts
- Automatic generation of reports from digital artifacts
- Central depository and "digital thread" throughout system development and retirement
- Changes in attitudes and culture within the established SE community
- Cyber Security required at all levels

Expected Benefits

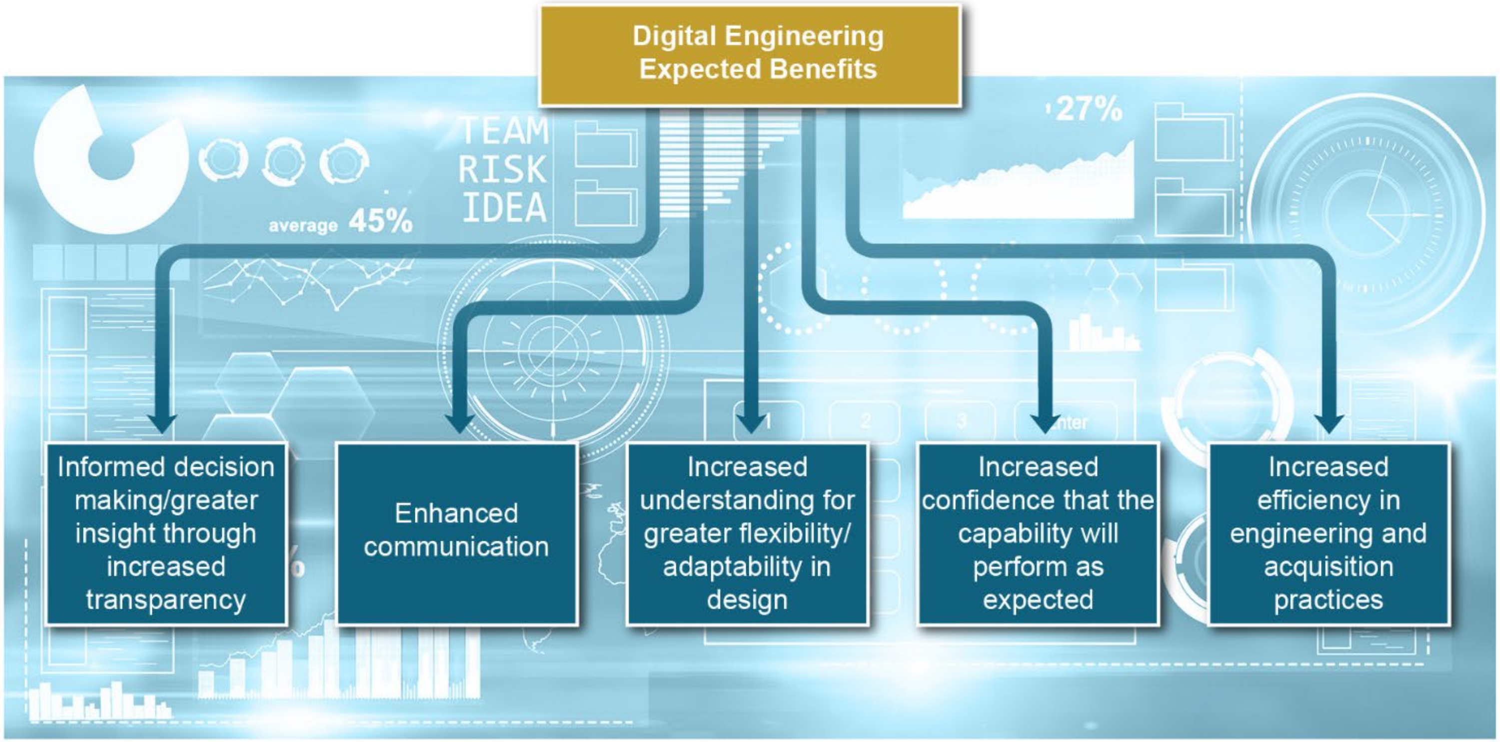


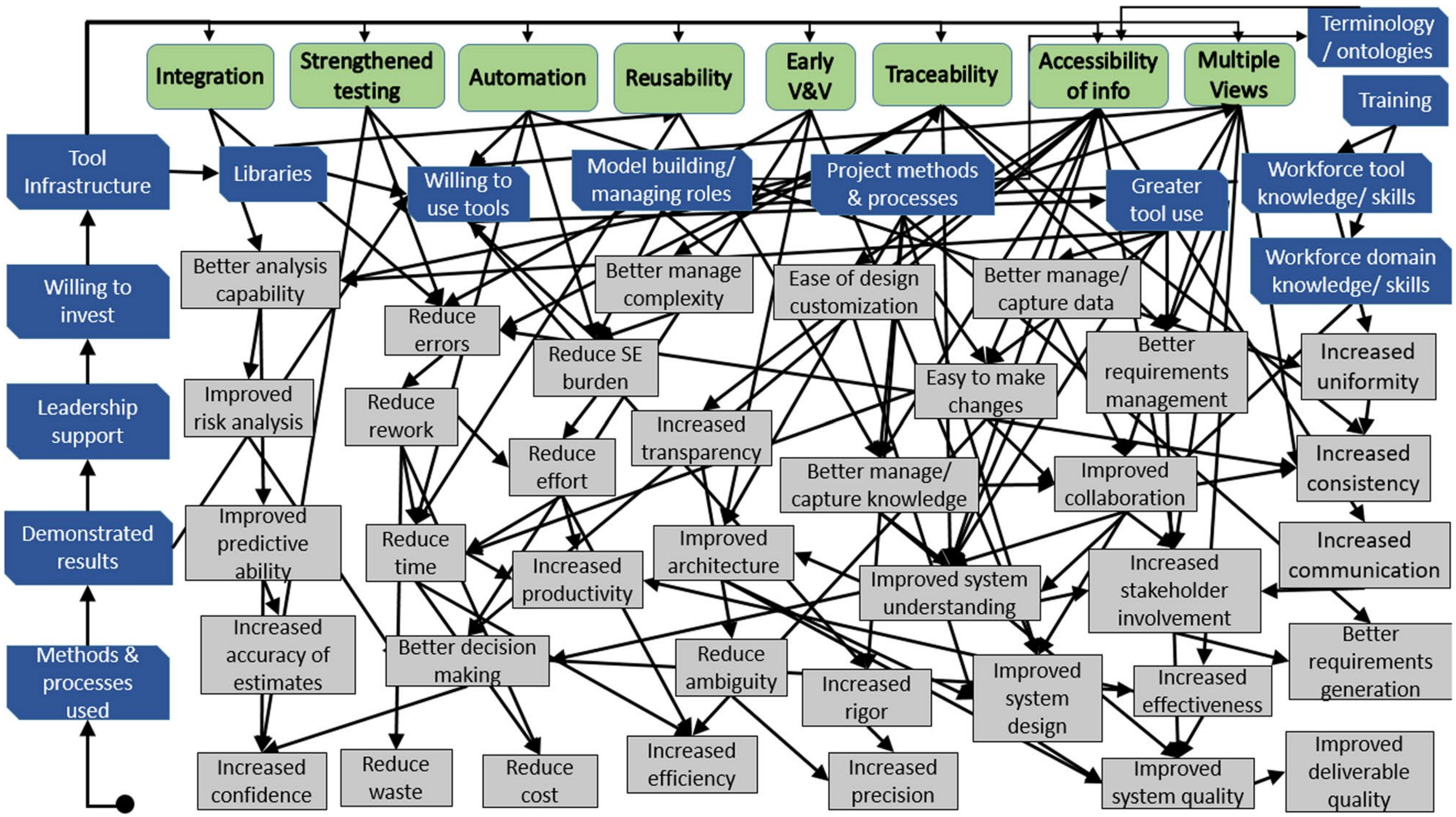
Figure 2: Digital Engineering Expected Benefits

DoD Digital Engineering Strategy June 2018
https://man.fas.org/eprint/digeng-2018.pdf

Benefits and Adoption Factors are Interrelated

CSU

This figures highlights recent work relating direct benefits (green), adoption factors (blue), and secondary or resulting benefits (gray) for DE



Towards Developing Metrics to Evaluate Digital Engineering
https://doi.org/10.1002/sys.21640

Parting Thoughts

CSU

Keep up with the digital evolution

- Digital engineers must keep up with the digital trends and make it a habit to explore and learn about them
- Organizations must do so as well

Learn how to use the tools, implement the processes, and code

- Fluency is required to realize the benefits

Soft skills still matter

- Not everyone may always understand the technical aspects, so digital engineers must bridge that gap through effective communication and collaboration

Diverse backgrounds and skills are important

- The aim should be to get different kinds of expertise, specialization, and backgrounds into a team to develop effective enterprise-level digital engineering approaches
- Building digital threads supports better communication and collaboration

What is digital engineering?
https://www.aurecongroup.com/expertise/digital-engineering-and-advisory/defining-digital-engineering

Outline

- Introduction
- Definitions and Concepts
- Case Studies
- Comments and Tips
- **Discussion Questions**

Discussion Questions

CSU

1. Where do you see a particular need for digital engineering or digital transformation more broadly?

2. What specific challenges have you observed or do you foresee with adopting digital engineering practices?

3. Do you have any digital engineering success stories you would like to share?

Transition to Digital Engineering: Case Studies and Concepts

Questions and Comments?

Select CSU SE Transformation Efforts

- Model-based Systems Engineering (MBSE)
- Digital Twinning (Batchelor, Herber, Simske, Vans)
- Digital Engineering (Batchelor, Herber)
- Augmented Reality/Virtual Reality (AR/VR) Environments and Classes (Vans)
- Secret Collateral Security Working area