A Reference Architecture for Digital Engineering Environments Supporting Digital Threads and Digital Twins

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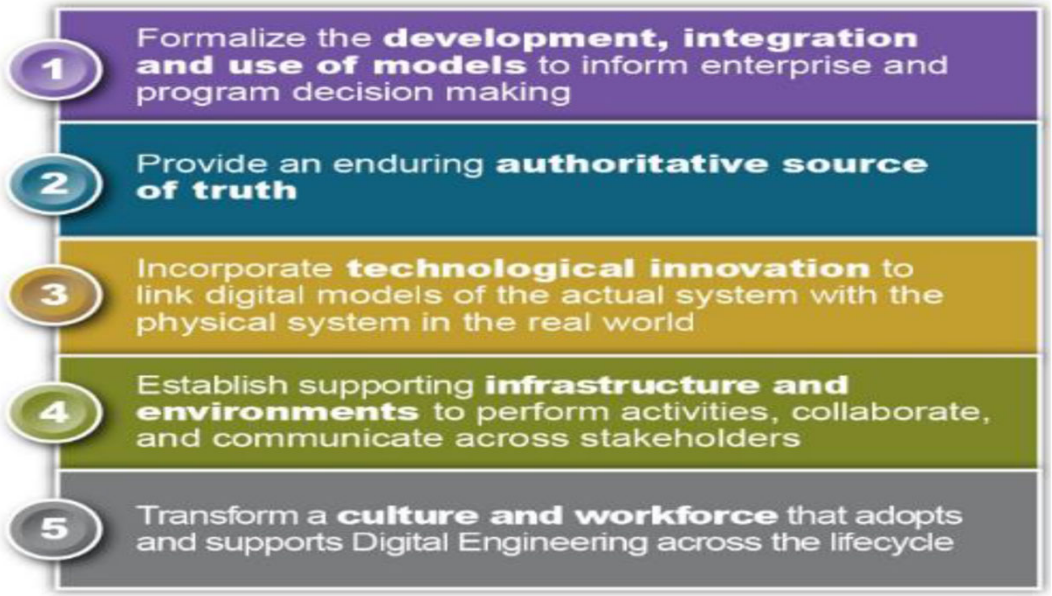
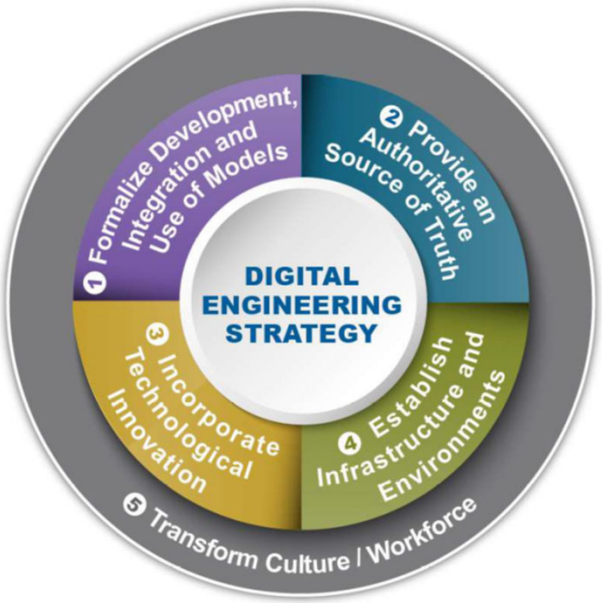
Presentation Outline

- Digital Engineering Strategy – Goals and Relevance
- Some Historical Examples of Collaborative Environments for Modeling & Simulation
- Reference Architecture for a Digital Engineering Collaborative Environment
  - Top-Level View
  - The Three Layers
  - The Two Overlays
- Illustrating Digital Threads Using the Reference Architecture
- Relationship of Digital Twins to the Reference Architecture and Digital Threads
- Summary

Digital Engineering Goals

- Digital Engineering: An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support life cycle activities from concept through disposal.





Source: "Digital Engineering Discussions", Philomena Zimmerman, NDIA Systems Engineering Division, May 2019

Digital Engineering Goals That Are the Focus of This Presentation

Digital Engineering Strategy Goal 2: Provide an Enduring Authoritative Source of Truth

- Provide an enduring authoritative source of truth
  - 2.1 Define the authoritative source of truth
    - Plan and develop the authoritative source of truth
  - 2.2 Govern the authoritative source of truth
    - Establish access and controls for the authoritative source of truth
    - Execute governance of the authoritative source of truth
  - 2.3 Use the authoritative source of truth across the lifecycle
    - Use the authoritative source of truth as the technical baseline
    - Use the authoritative source of truth to produce digital artifacts, support reviews, and inform decisions
    - Collaborate and communicate using the authoritative source of truth

Digital Engineering Strategy Goal 4: Develop a Supporting Infrastructure and Environments

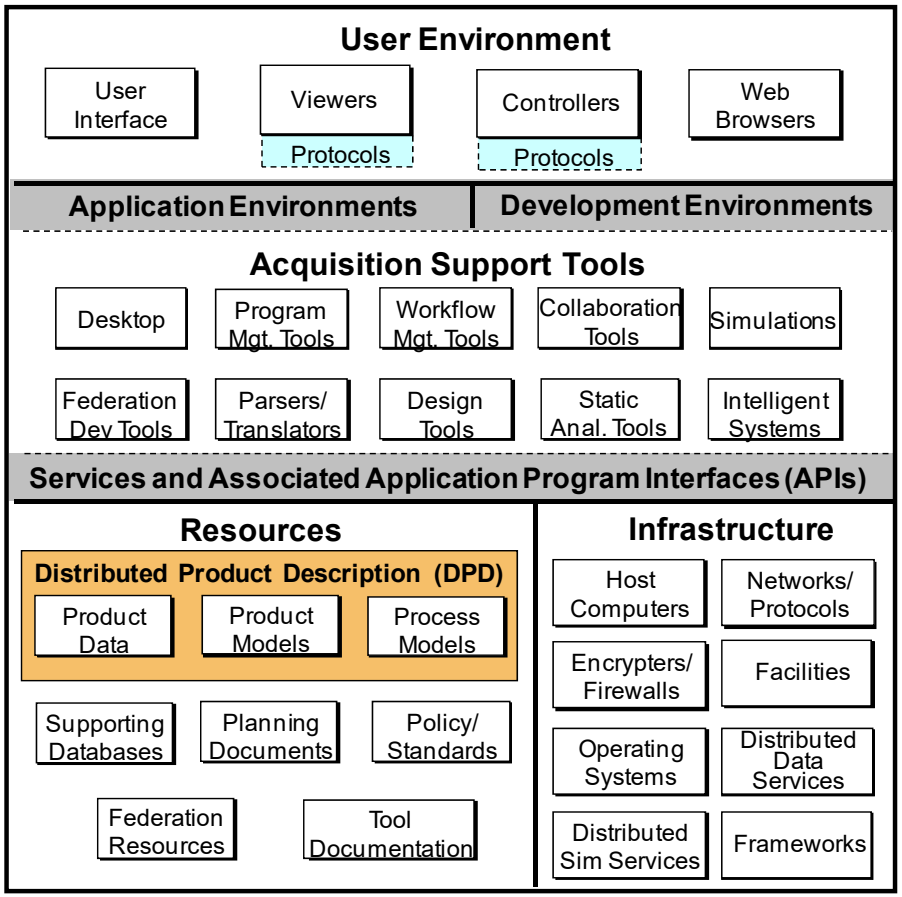
- Develop a supporting infrastructure and environments to perform activities, collaborate, and communicate across stakeholders
  - 4.1 Develop, mature, and use digital engineering IT infrastructures
    - Provide hardware and software to perform digital engineering activities
  - 4.2 Develop, mature, and use digital engineering methodologies
    - Develop, mature, and implement methods and processes to support digital engineering activities across the enterprise and lifecycle
    - Develop, mature, and implement digital engineering tools
  - 4.3 Secure IT infrastructure and protect intellectual property
    - Protect intellectual property while using models to collaborate throughout a program lifecycle

Digital Engineering Strategy Goal 4: Develop a Supporting Infrastructure and Environments

Goal 4.1: Digital engineering IT infrastructures include a collection of hardware, software, networks, and related equipment. They span geographical locations and organizations, and they must satisfy security requirements. …

Source: *Digital Engineering Strategy*, June 2018

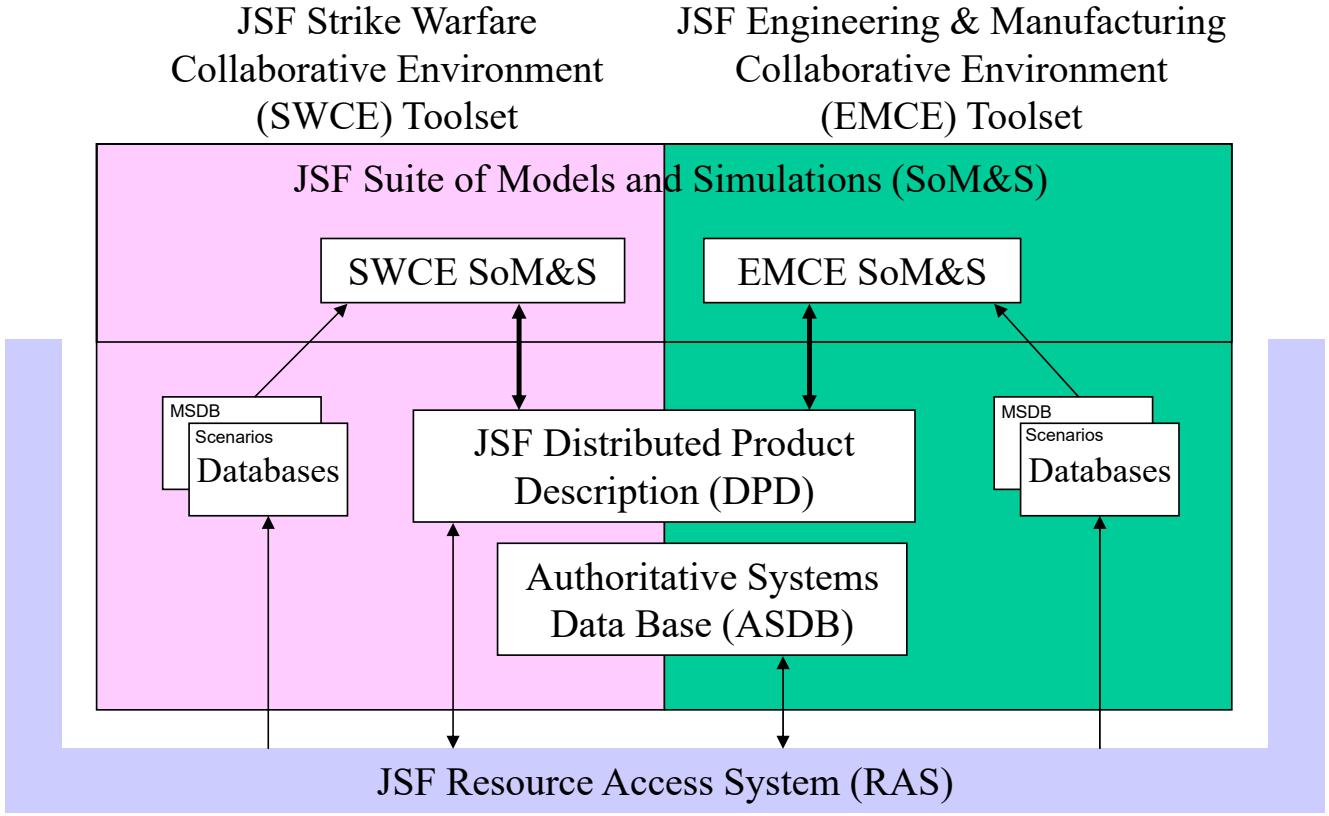
A Sample Reference Architecture for a Collaborative Environment (source: SBA Roadmap, 1998)



Notes:

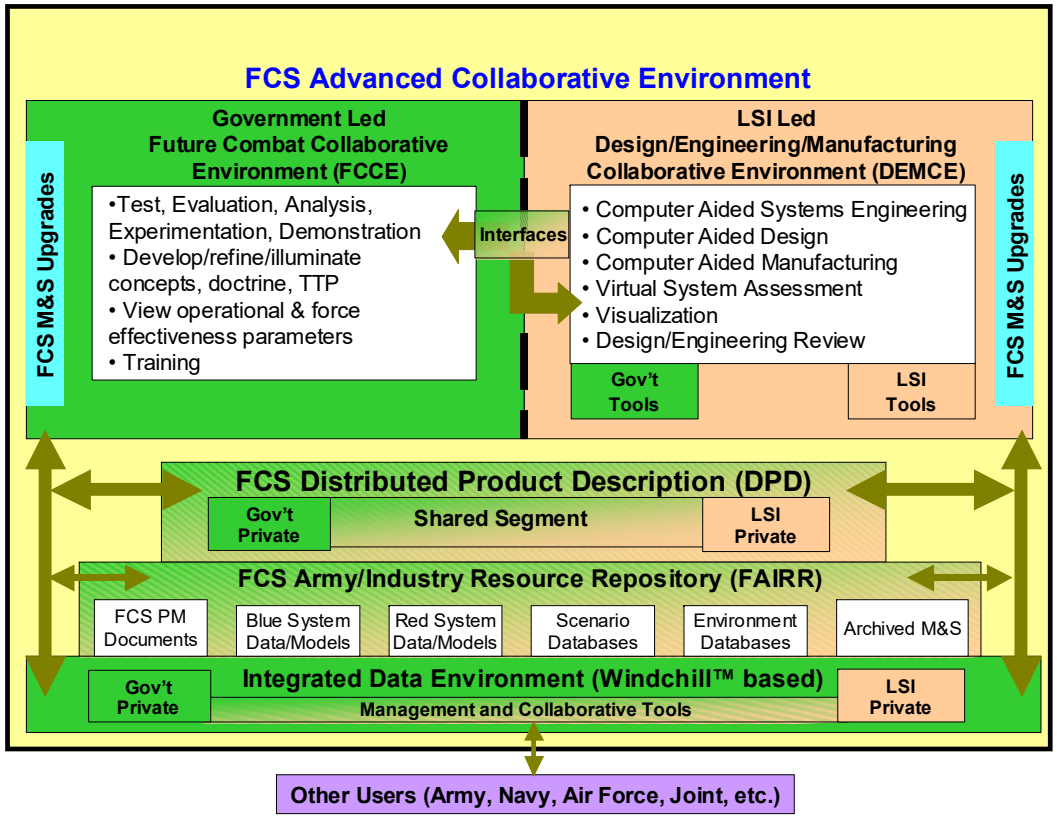
- Intended as an overall framework
- Every component type need not be represented in every Collaborative Environment

An Example Collaborative Environment Architecture – the Joint Strike Fighter (JSF) Program, 2000



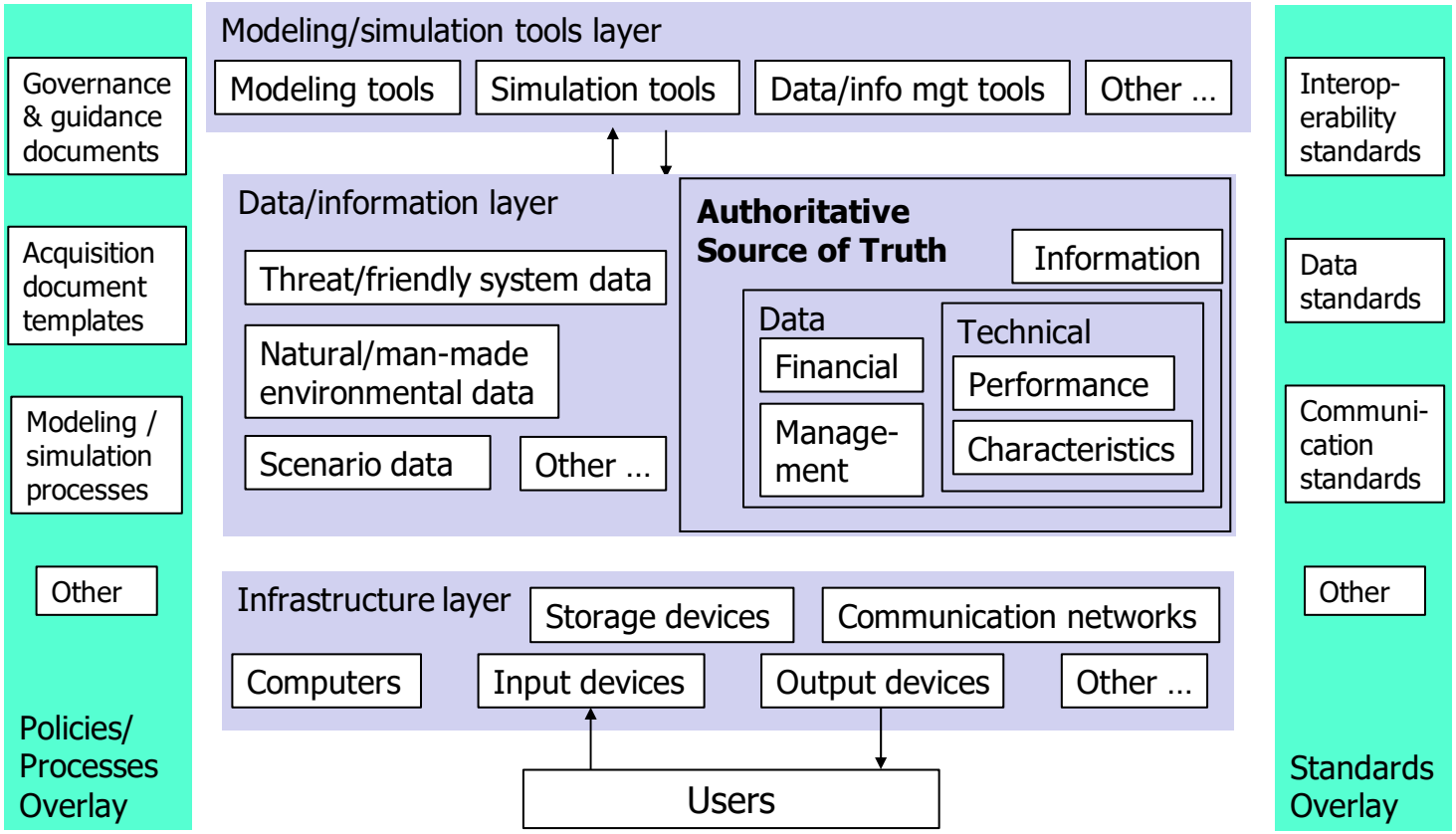
Source: "The Joint Strike Fighter (JSF) Strike Warfare Collaborative Environment (SWCE)," in *Proc., 2000 Fall Simulation Interoperability Workshop*, Simulation Interoperability Standards Organization, September 17-22, 2000, Orlando, FL.

An Example Collaborative Environment Architecture – the Future Combat Systems (FCS) Program, 2001



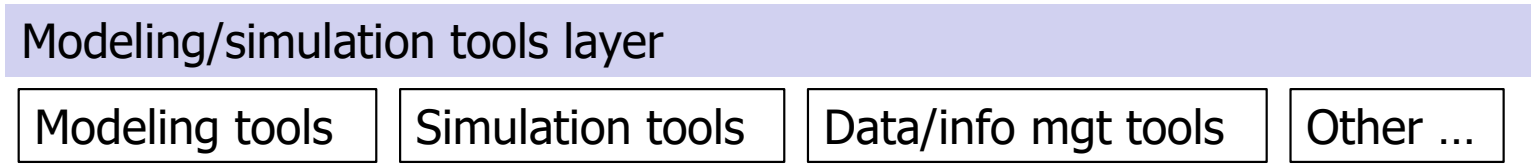
Source: Defense Advanced Research Projects Agency (DARPA) Solicitation No. PS 0207, "DARPA / Army Future Combat Systems Program Solicitation," November 2001.

A Collaborative Environment Centered on the Authoritative Source of Truth



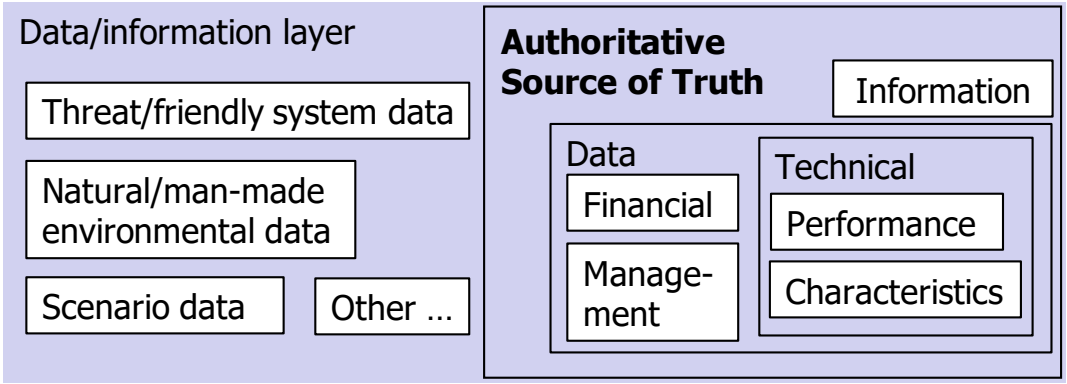
Adapted from: "A System-Model-Centric Collaborative Environment for the Acquisition Lifecycle," J.E. Coolahan and J.J. Bergenthal, 2015 Interservice/Industry Training, Simulation & Education Conference, Nov.-Dec. 2015.

The Modeling/Simulation Tools Layer – Contents



- Modeling tools (e.g., for Computer-Aided Design, manufacturing processes)
- Software-based simulations (e.g., for performance / effectiveness estimation, supportability)
- Hardware-in-the-loop simulations
- Data and information management tools (e.g., Product Data Managers, M&S tool catalogs)
- Simulation interoperability tools (e.g., High Level Architecture implementations)

The Data/Information Layer – Contents



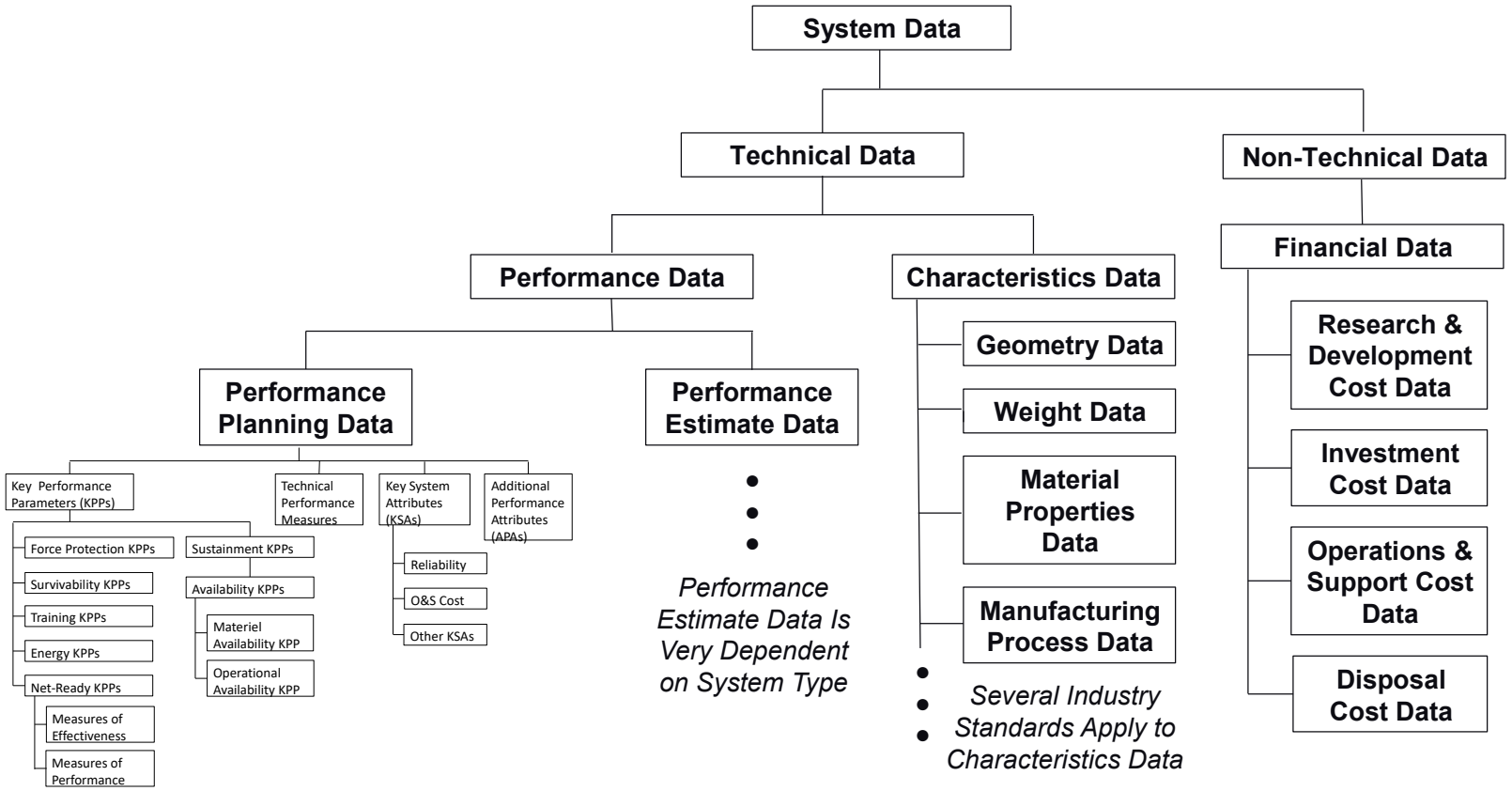
The Authoritative Source of Truth

- Information (e.g., documents on the system needed for acquisition)
- Authoritative data (many types; see next slide)
  - Will grow significantly over time
  - Likely to be physically distributed across government and contractors

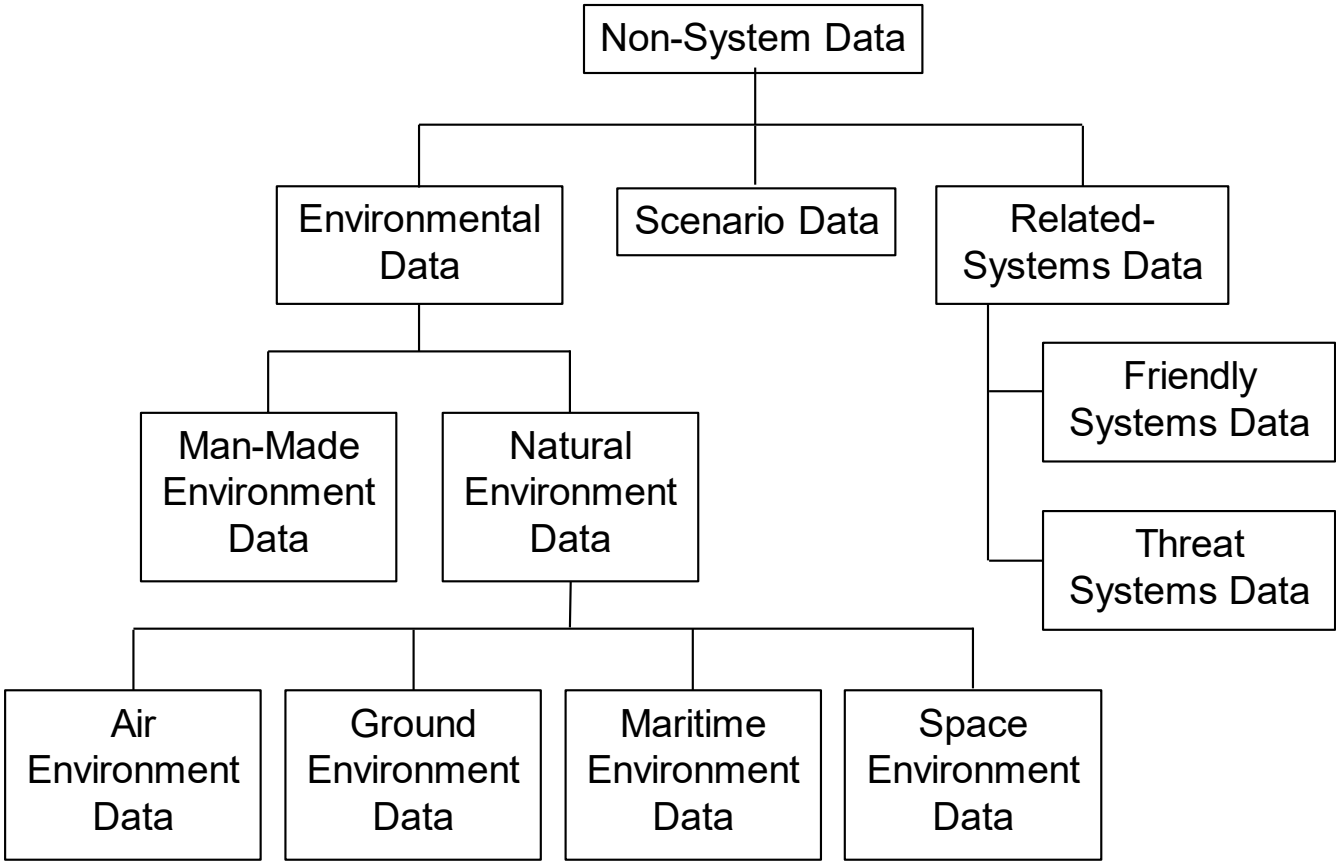
"Non-System Data" (see slide after next)

- Threat/friendly systems, environment, scenarios

A Potential Top-Level Taxonomy for Data in an Authoritative Source of Truth

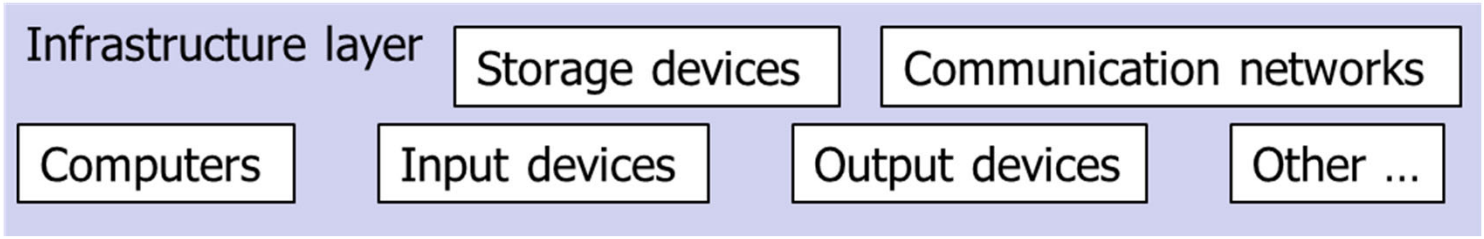


A Categorization of "Non-System" Data

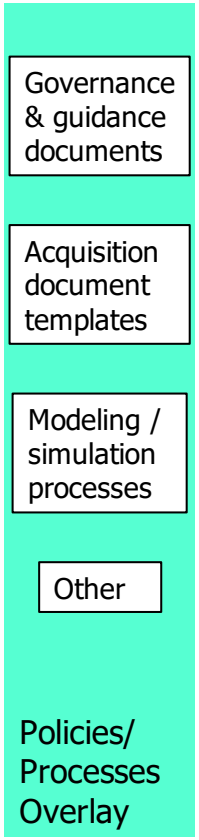


The Infrastructure Layer – Contents

- Computers
- Software
- Networks
- Special-purpose hardware



The Policies/Processes Overlay – Contents



- Governance document(s) delineating organizational responsibilities for maintaining the collaborative environment components and elements
- Security guidance documents for classified elements of the collaborative environment
- Acquisition document templates
- Configuration management processes for the Authoritative Source of Truth and other elements of the data/information layer
- Verification, validation, and accreditation (VV&A) processes for elements of the modeling/simulation tools layer
- Distributed simulation systems engineering processes for simulation federations

The Standards Overlay – Contents

- Simulation systems engineering and interoperability standards
- Data standards for
  - System characteristics data
  - System performance data
  - Manufacturing data
  - Financial data
  - Environmental data
  - Scenario data
- Communication protocol standards
- Modeling and markup language specifications
- Process standards (may overlap with Policies / Processes Overlay)

Digital Thread and Digital Twin Definitions from the Defense Acquisition University (DAU) Glossary

Digital Thread: An extensible, configurable and component enterprise-level analytical framework that seamlessly expedites the controlled interplay of authoritative technical data, software, information, and knowledge in the enterprise data-information-knowledge systems, based on the [Authoritative Source of Truth] template, to inform decision makers throughout a system's life cycle by providing the capability to access, integrate and transform disparate data into actionable information.

Digital Twin: An integrated multiphysics, multiscale, probabilistic simulation of an as-built system, enabled by the Digital Thread, that uses the best available models, sensor information, and input data to mirror and predict activities/performance over the life of its corresponding physical twin.

Alternate Definitions of a Digital Thread

The use of digital tools and representations for design, evaluation, and life cycle management. [1]

A data-driven architecture that links together information generated from across the product lifecycle. [2]

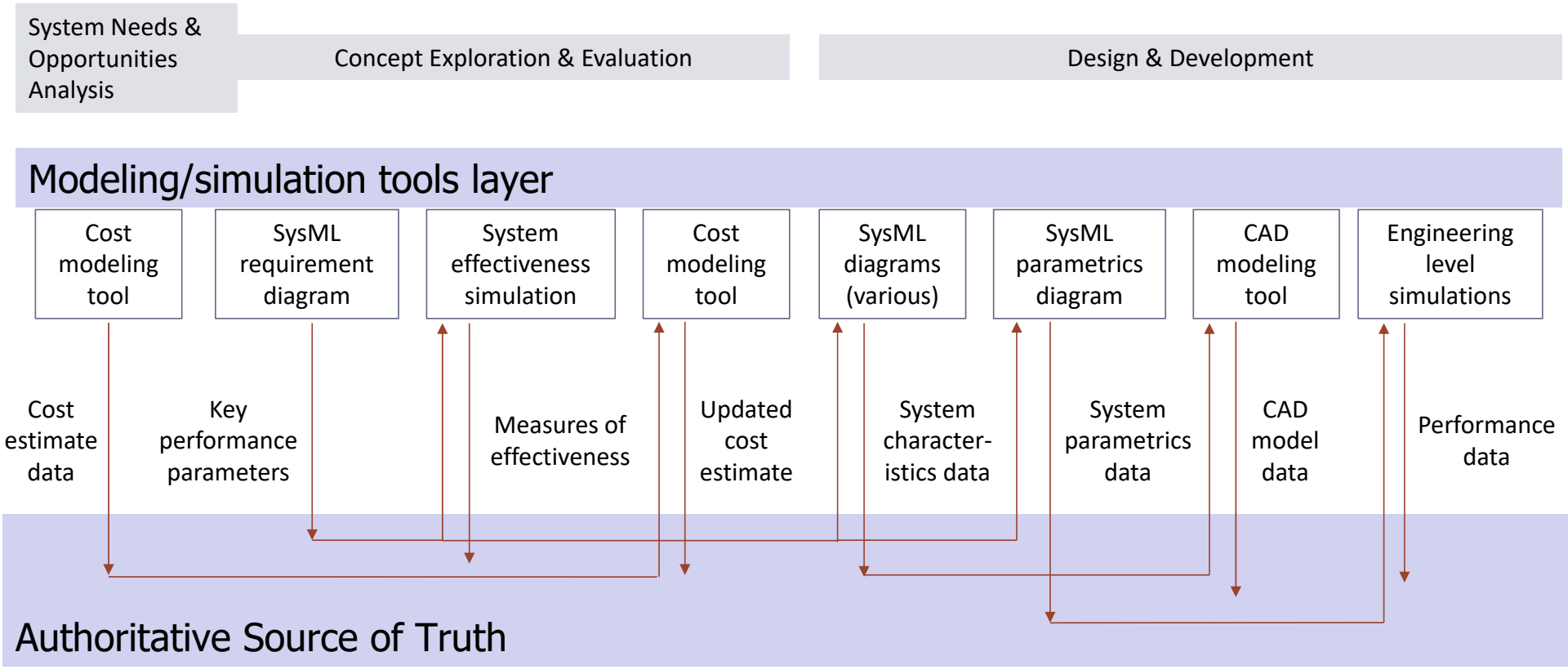
An integrated information flow that connects all the phases of the product lifecycle using accepted authoritative data sources, e.g. requirements, system architecture, technical data package, 3D CAD models, and project tasks. [3]

[1] USAF Global Science and Technology Vision Task Force. "Global Horizons Final Report". 2013.

[2] Singh, V. and Willcox, K. "Engineering with a Digital Thread". 2018.

[3] Bajaj, M. and Hedberg, T. "System Lifecycle Handler – Spinning a Digital Thread for Manufacturing". 2018.

The Digital Thread in a Collaborative Environment
A Partial Example



Alternate Definitions of a Digital Twin

A high-fidelity model of the system which can be used to emulate the actual system. [1]

A digital twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision-making. [2]

A digital twin is a digital representation of a real-world entity or system. The implementation of a digital twin is an encapsulated software object or model that mirrors a unique physical object, process, organization, person or other abstraction. [3]

… and many more.

[1] Guide to the Systems Engineering Body of Knowledge. https://www.sebokwiki.org/wiki/Digital_Engineering

[2] IBM website, https://www.ibm.com/topics/what-is-a-digital-twin

[3] Gartner website, https://www.gartner.com/en/information-technology/glossary/digital-twin

A Proposed Definition of a Digital Twin

Premise: No single model, simulation, and/or dataset can represent all characteristics and performance measures of a major system that will meet the needs of all stakeholders.

Proposed definition: A digital twin is a unified consistent set of models, simulations, and data that represents all of the characteristics and performance measures of a system at a particular point of time in the lifecycle of a system at a sufficient fidelity to meet the needs of all stakeholders of the system.

Examples:

For a mechanical engineer designer of a system, the digital twin is a representation of the form and fit of all components, and related tolerances, of a system at a particular point of time in the lifecycle of the system.

For a performance evaluator of a system, the digital twin is a representation of the functional performance of the entire system at a particular point of time in the lifecycle of the system.

Summary

A goal of the DoD Digital Engineering Strategy is to develop a supporting infrastructure and environments.

A working definition of a collaborative environment for system acquisition has existed since at least 1998.

Elements of a collaborative environment include a purpose, people, tools, standards, and processes.

A Digital Engineering Collaborative Environment can be used to implement Digital Engineering concepts, including Digital Threads and Digital Twins.