Development of Digital Engineering Artifacts in support of MBSE-based Test Planning, Execution, and Acquisition Decision Making

May 2023

Table of Contents

Abstract and Introduction

Many related efforts are underway throughout the DOD and DOT&E's Strategic Initiatives, Policy, and Emerging Technologies (SIPET) division has sponsored Model-Based TEMP (MBTEMP) Workshops at Johns Hopkins University Applied Physics Laboratory (JHU/APL) in July 2022 and Feb 2023 to foster collaboration and knowledge exchange to advance MBSE for T&E.

Most of these efforts are looking at one of three paths for creating MBTEMPs:

1. Digitizing the current acquisition artifacts

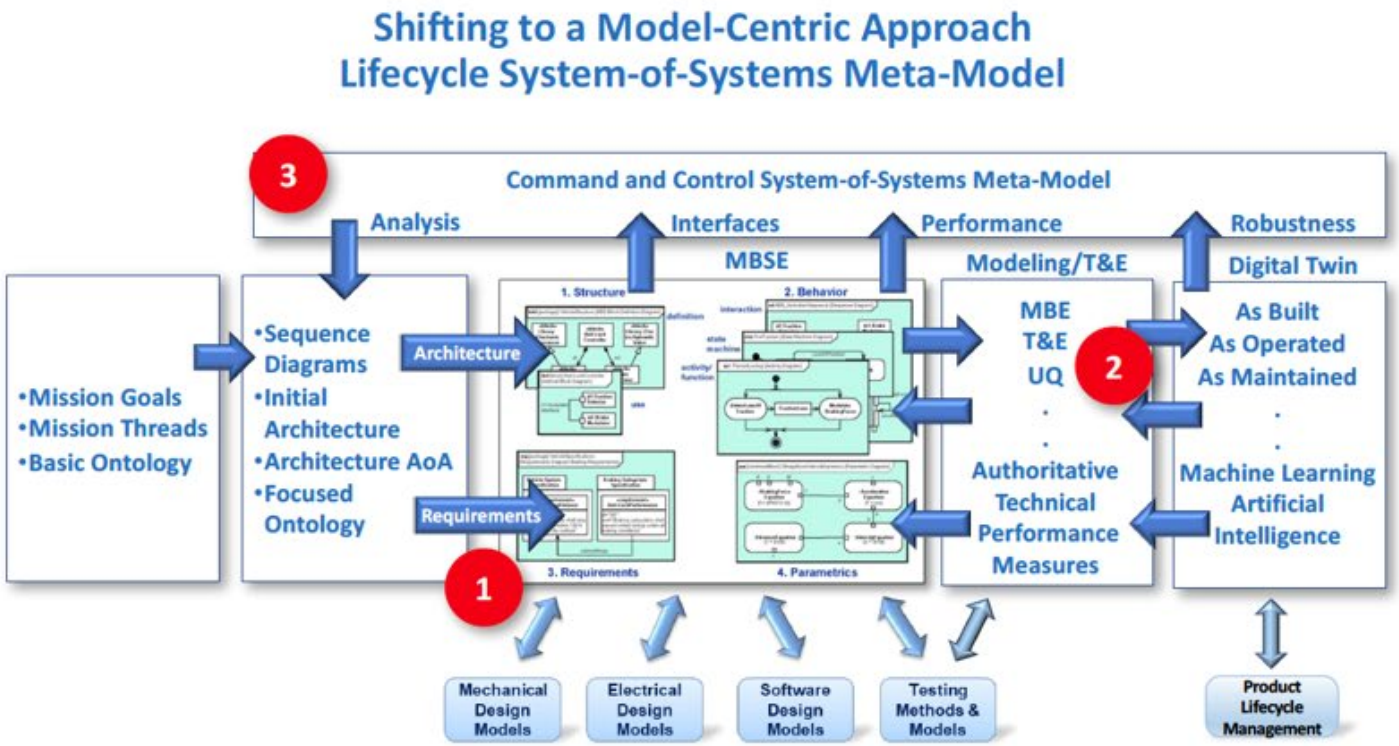
2. Creating a hybrid MBTEMP based on the current format and integrating with different models that are being developed within MBSE environments

3. The development of a completely new method to do T&E planning in a model-based system

The transformation from the historical, document-based acquisition system to DE is resulting in some of the most significant changes to the way the DOD has engineered and developed weapon systems in decades. The shift to the use of DE will not only impact the DOD but the entire military industrial complex.

The **creation of artifacts is a critical part of the acquisition process** as these artifacts are used to manage acquisition processes and decisions. As part of the effort to digitize the acquisition and the engineering process, these artifacts also **need to be digitized**; the need **to provide decision maker better data** to make decisions is one underlying diver for digitizing these artifacts. One of the key acquisition artifacts that needs to be digitized is the Test and Evaluation Master Plan (TEMP) that captures the key elements of acquisition programs' T&E strategy and associated resources and schedule.

Lifecycle System of Systems Meta-Model



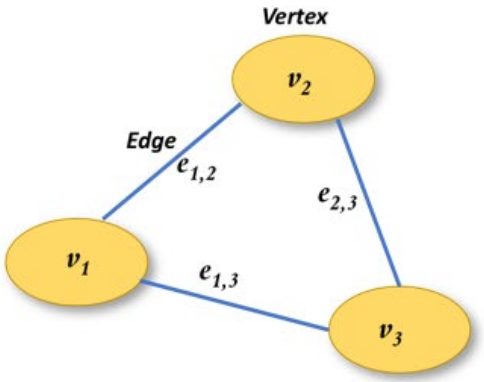
1. Descriptive models describe logical relationships, such as the system's whole-part relationship that defines its parts tree, the interconnection between its parts, the functions that its components perform, or the test cases that are used to verify the system requirements. Descriptive models are developed and managed through *Models Based Systems Engineering (MBSE)* tools and processes.
2. Analytical models describe mathematical relationships, such as differential equations that support quantifiable analysis about the system parameters. Analytical models are typically physics-based models developed and applied through *Model Based Engineering (MBE)* tools and practices.
3. System models can be hybrid models that are both descriptive and analytical. They often span several modeling domains that must be integrated to ensure a consistent and cohesive system representation. *Mission engineering and system of systems authoritative virtualization* require system models.

Model-Based TEMP Workflow

A workflow for developing MBTEMPs links mission and systems engineering to the IDSK shifting left (and looking right) through the development of early (and late) virtual integrated and operational test. The approach emphasizes using graph theory and iterative analysis as the mathematical basis for injecting testing of mission threads via mission model simulations, both early and often.

Graph Theoretic Approach

- Graphs are executable using inference engines testing for consistency and composability and represent run-time models of a digital data thread through an architecture. Aggregated together, these digital data mission threads can represent a Run-Time environment of a specific architecture.
- The lessons learned continue to tell us that it is the interfaces, interactions and software driven data movement across these interfaces for a given operational goal in a specific employment configuration that drive programs red
- The digital mission thread models are based on State Machines and become a testable simulation.
- This basis pushes iterative analysis of many architecture alternatives early in the lifecycle, focuses on goal-based mission threads and early risk reduction of the areas that will cause costly problems later in the lifecycle.
- The shift to graph theory allows us to inject testing of mission threads via mission model simulations in the mission context early and often – *the basis for an integrated virtual operational test .*



$$e_{j,k} = e_{k,j}$$

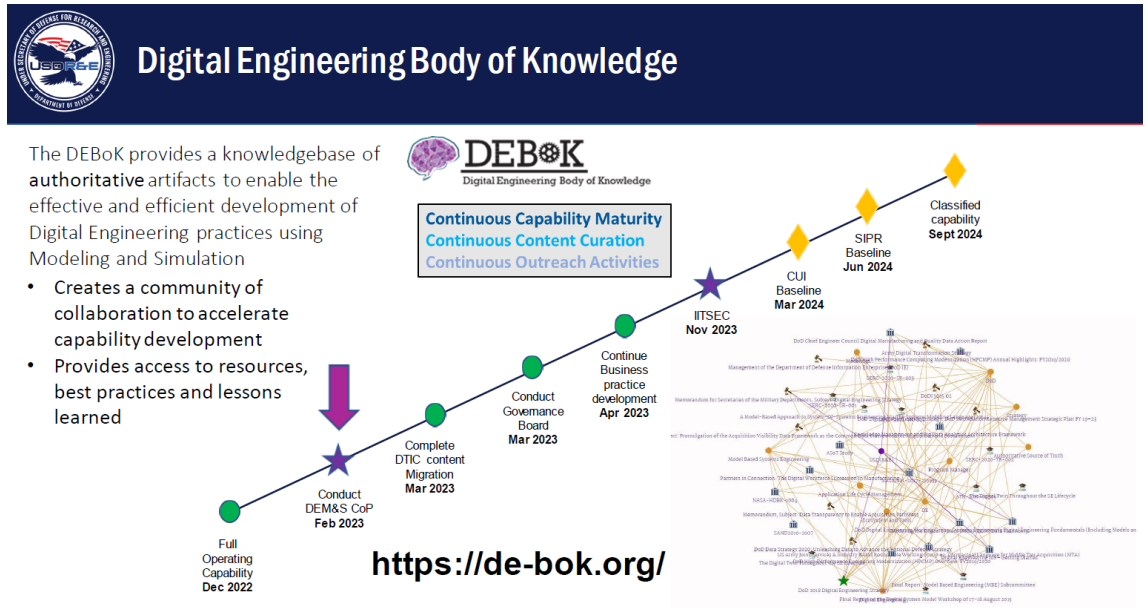
Digital/Mission Engineering

R&E SE&A's views on digital and mission engineering with a T&E focus Digital Engineering, Modeling & Simulation (DEM&S, R&E, SE&A). DEM&S's vision for Digital Engineering was conveyed as:

1. Digital becomes the normal
2. Data & Information flow across disciplines and ecosystems throughout the lifecycle
3. Powerful modeling, simulation, and visualization tools are used
4. AI is used to elevate experts and gain insights
5. Decisions are data driven and made with confidence earlier
6. Innovative culture is adaptive and continuously improves practices across the Defense Acquisition Lifecycle

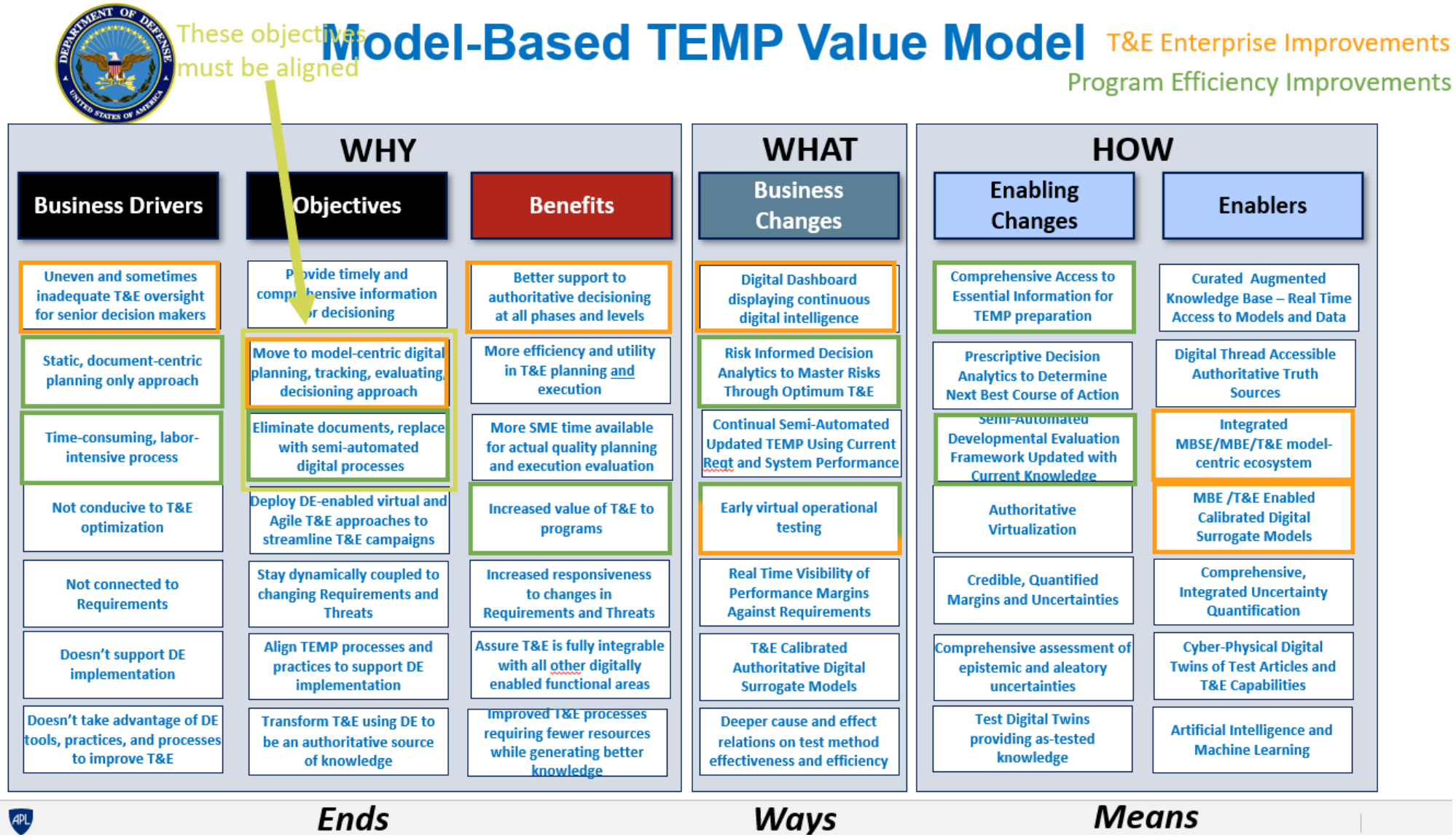
with the goals of:

- Outpacing rapidly changing threats and technological advancements
- Delivering advanced capabilities more quickly and affordably with improved sustainability to the warfighter
- DEM&S's near-term focus is on advancing a community of practice and body of knowledge for digital engineering



MBTEMP Roadmap and Vision

Roadmap including a POAM with scheduled roll-out of MBTEMP solutions and outreach to future pilot programs.



DOT&E S&T Initiatives

An update on DOT&E's science and technology plan and associated implementation plan. The implementation plan is aligned to DOT&E's five strategic pillars shown below and its overarching goal of: *Transforming T&E to enable delivery of the world's most advanced warfighting capabilities at the speed of need.*

DOT&E Strategy Implementation Plan Overview

DOT&E's Implementation Plan guides decisions and actions across the entire T&E enterprise to resource, develop, and sustain tools, methods, processes, and the infrastructure needed to support credible evaluation of the future Joint Force.

APPROACH

The Implementation Plan has five strategic pillars and key actions needed to meet high-level objectives.

Test the way we fight	Accelerate the delivery of weapons that work	Improve survivability of DoD in a contested environment	Pioneer T&E of weapon systems built to change over time	Foster an agile and enduring T&E enterprise workforce
Field systems and technology to support Joint Force strategies.	Move T&E into secure, modern-day standards with automation and data.	Quickly identify mission-critical vulnerabilities .	Evaluate new technologies in credible, efficient, and continuous manner.	Train and equip the T&E workforce to meet toughest challenges.

TIMELINE

The I-Plan features initiatives that will be rolled out in FY23.

Finalize all feedback and edits to I-Plan	Kick off Pillar initiatives and begin baselining I-Plan metrics	Roll out new methods, solutions, and testing products	Review I-Plan to solicit changes to existing initiatives and identify new initiatives
OCTOBER 2022	JANUARY 2023	SEPTEMBER 2023	OCTOBER 2023

Digitally Implementing IDSK as a Relational Database

A proof of concept implementing an IDSK as a Relational Database Using the Mk 54 Lightweight Torpedo as an exemplar was presented. All related tables from the Jan 2021 draft of the Mk 54 Lightweight Torpedo TEMP were integrated into this relational database. The IDSK database was implemented in two languages: R Project, which is popular among the T&E analyst community, and SQLite, which is the world's most popular enterprise SQL database engine and was invented as part of a Navy project that developed software for Arleigh-Burke-class destroyer's damage control.

Smart Documentation from Edaptive Computing

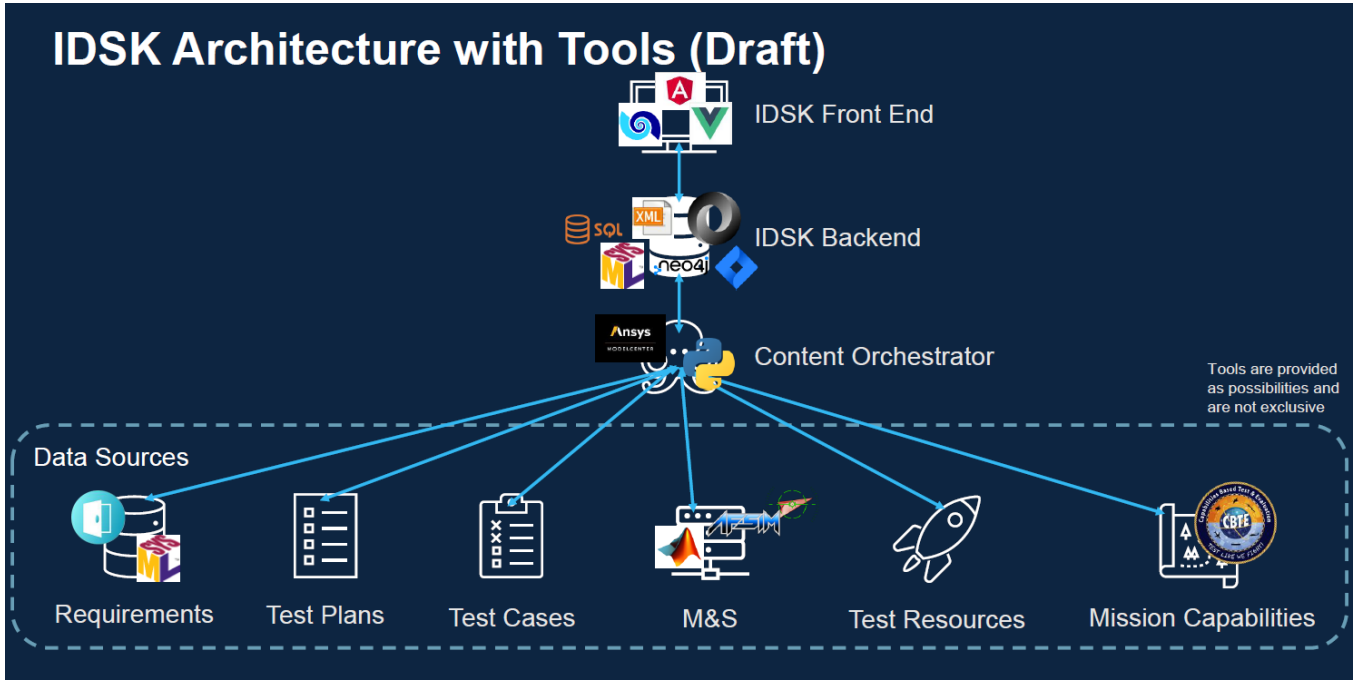
A mature model-backed word processing and document content management system that Edaptive is enhancing for MBTEMP was demonstrated. The solution stores content modules (e.g., system descriptions) in a backend database so that they can be used across multiple documents in a version-controlled way. The solution is integrated into Microsoft Word so that document developers can continue to work in their native environment. The system is currently being enhanced to pull IDSK tables into Microsoft Word-developed TEMPs from a backend SQL database. A future iteration will enable the full generation of IDSK databases directly within the web app from a set of templates without the user needing to have any knowledge of SQL.

IDSK Concept & Digital Implementation Vision

A concept for IDSK and vision for implementing it digitally was presented. The concept described how IDSKs can be used to enable better programmatic decision making. It was discussed how the IDSK can articulate a logical evaluation strategy to inform decisions. IDSKs can convey:

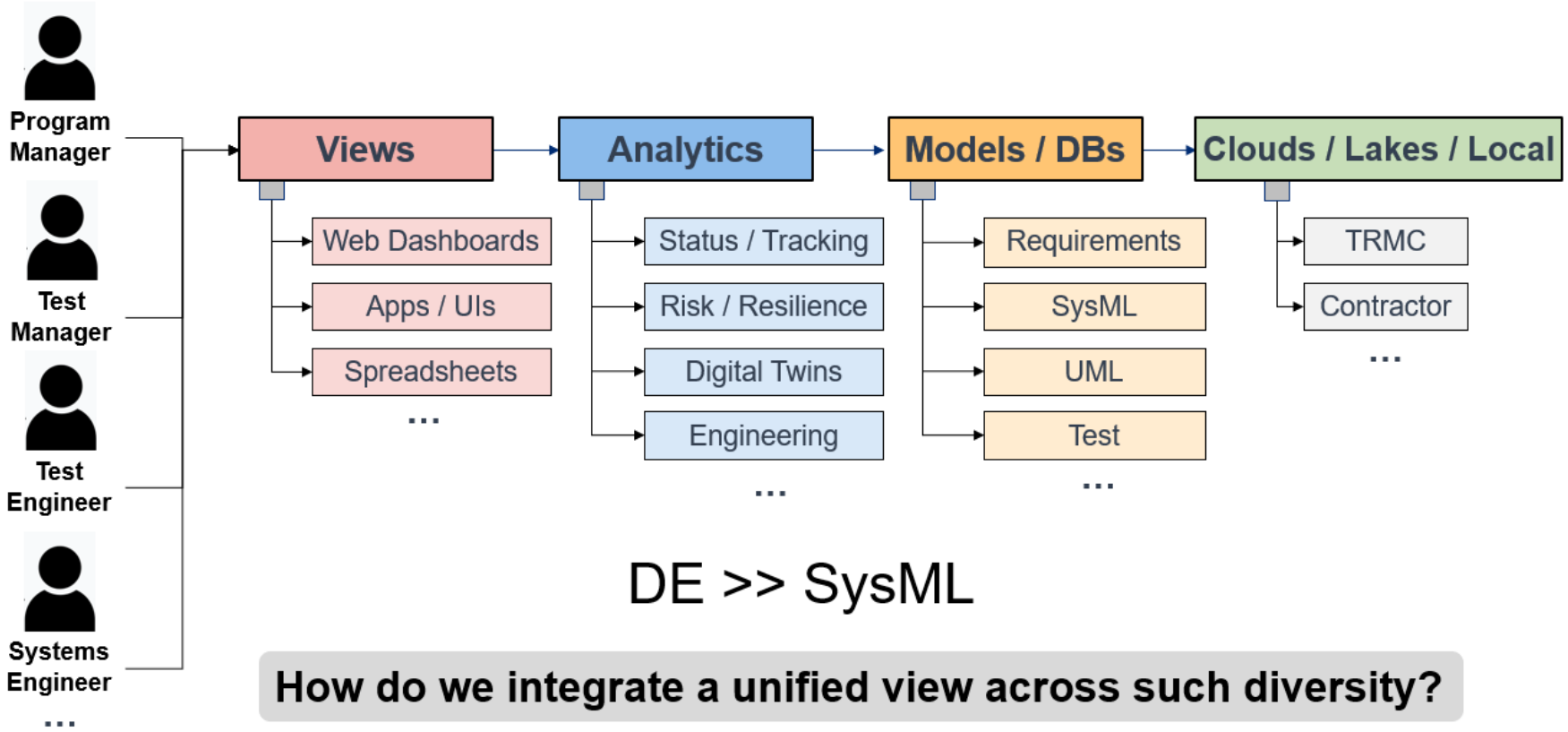
- Decisions to be made and knowledge needed for informed decisions.
- Operational and technical capabilities evaluation to generate knowledge.
- Wargames, experimentation, M&S, test events, analyses and other data sources provide data for evaluation

Their vision for implementing the IDSK using a variety of tools was then discussed, as seen in the figure below.



MBTEMP Profile/ Data Dashboard

A conversation occurred about creating MBTEMP profiles in SysML and connecting them and their underlying data to dashboards for analytics. The question of "how can we identify and locate test-relevant digital model data for a variety of T&E stakeholders?" was discussed from multiple different viewpoints including MBSE and the more traditional data engineering approaches used across the modern business enterprise (e.g., SQL).

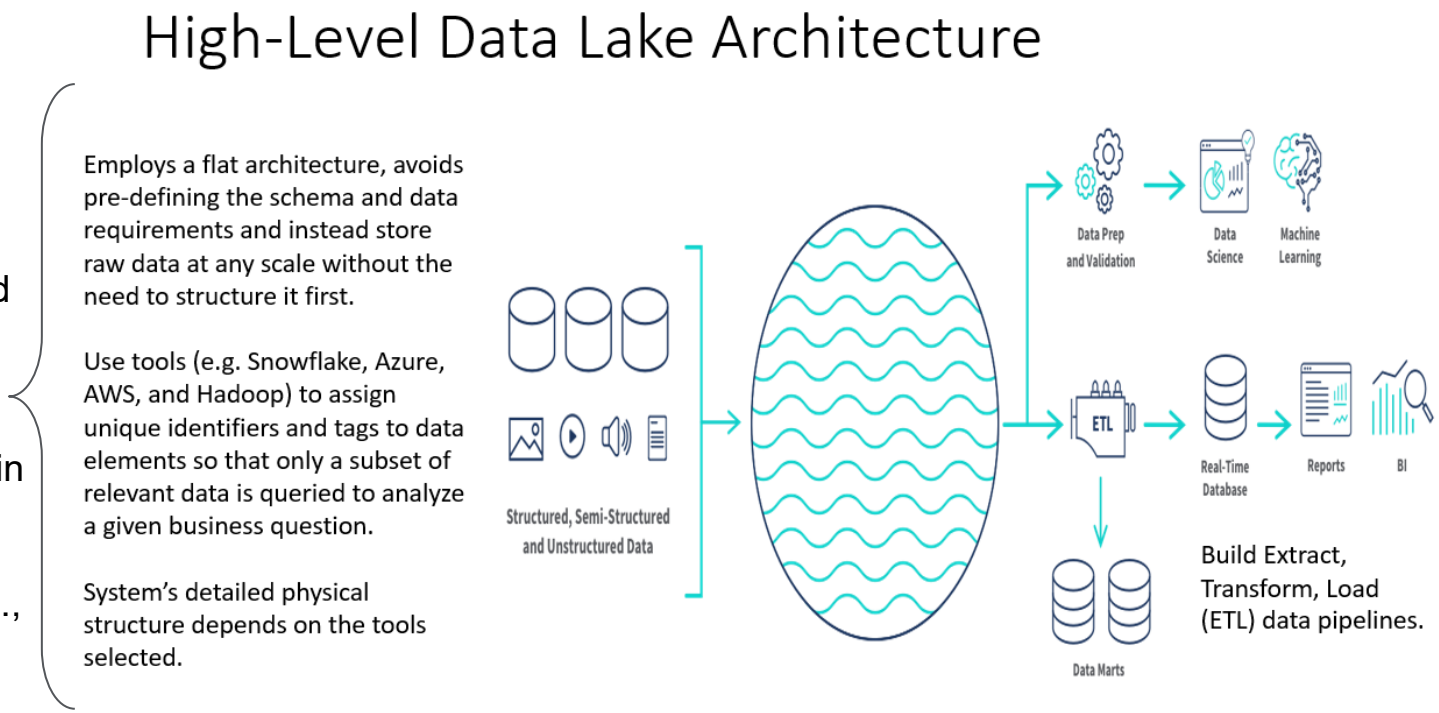


Torpedo Exemplar

There was a presentation of the MBTEMP exemplar of the Mk 54 lightweight torpedo. The analytic augmentation of this MBTEMP to act as an acquisition milestone decision-support planning tool was discussed. The SysML models of both the TEMP elements (e.g., system description) and the actual system (e.g., guidance and control) were displayed and then put into a unified mission context for T&E to assess the system's operational effectiveness, suitability, reliability, and lethality.

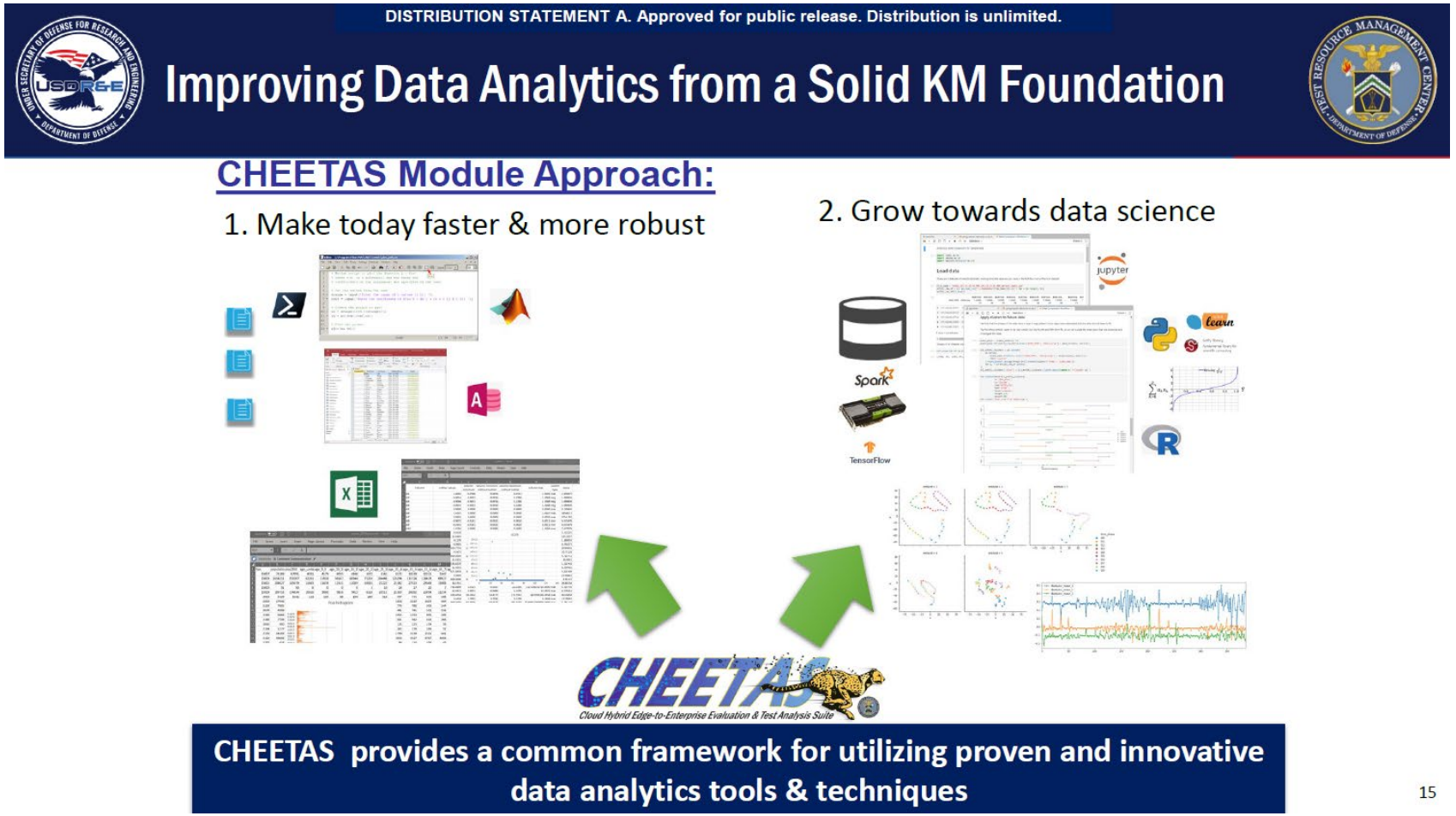
Enterprise Data Lake

Solutions like data lakes, data warehouses, and data marts were all discussed, as were their advantages and disadvantages, and included their associated extract, transform, load (ETL) processes, and the types of live end-user applications such as analytics and machine learning they can support. This was all contextualized in terms of DOT&E's vision for building a common, automated data and data analysis environment for the T&E enterprise – all the way from the tactical edge (e.g., test range) to the C-Suite (e.g., Advana).



TRMC MBTEMP Supporting Capabilities

JMETC is providing an agile infrastructure to enable rapid acquisition wit the desired result of providing an “an operationally-realistic environment for rapid experimentation, testing, training, and mission rehearsal across warfighting domains.” TRMC’s related investment areas include TENA, the JMETC nramp, CHEETAS—which, among other things, provides a tactical system-to-engineering units data interoperability layer—and many others. CHEETAS has a central role in TRMC’s upcoming investments in knowledge management, big data analytics, and data science capabilities.



MBTEMP Analytics

A MBTEMP can be used in conjunction with analytics to answer a variety of stakeholder questions.

What if You Could Ask the TEMP Questions?

What would you want to know?

What is the status of test event scheduling?

- For which requirements have test events been planned?
- Which are not yet planned?
- For which system components have test events been planned?
- Which are not yet planned?

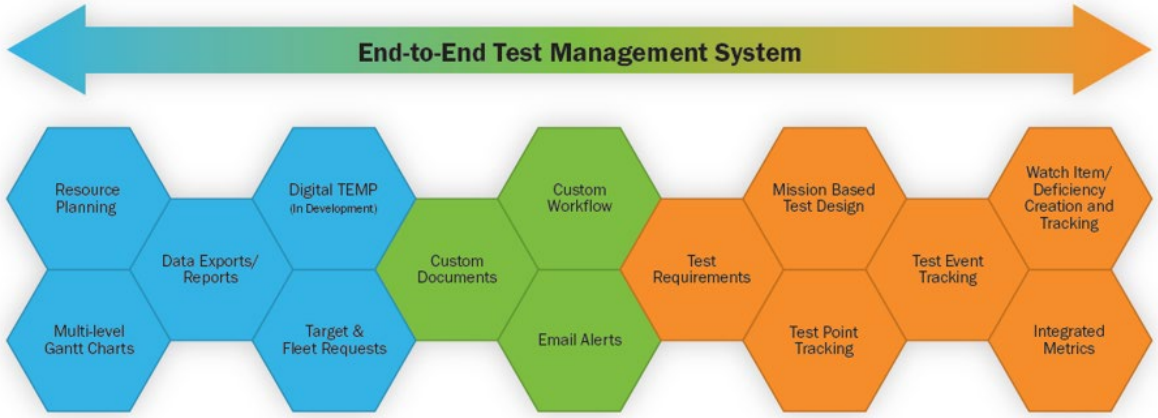
Where in the system should tests be focused?

- What are the most critical system components?
- What are the most lightly defended (highly exposed) components?
- What mitigations are missing?
- What mitigations are present, but not beneficial?

A model-based TEMP provides enhanced abilities for automated analytics compared to a document-based TEMP.

Integrated Test & Evaluation Management System (iTEMS) Update from Navy

The Integrated Test & Evaluation Management System (iTEMS) is a suite of web-based software applications. iTEMS was developed in an effort to streamline the tools currently used across multiple DoN Programs and platforms. It leverages existing tools, best practices, and lessons learned to reduce development and operation costs. Through the use of iTEMS – data is used, controlled, and expelled in a consistent and measurable manner, providing data consolidation and accurate translation.



iTEST

Program Scheduling & Tracking

High level resource and scheduling tool for planning used primarily by APMT&Es. Department of the Navy Fleet Resource Requests are also processed through iTEST.

iPlan & iReport

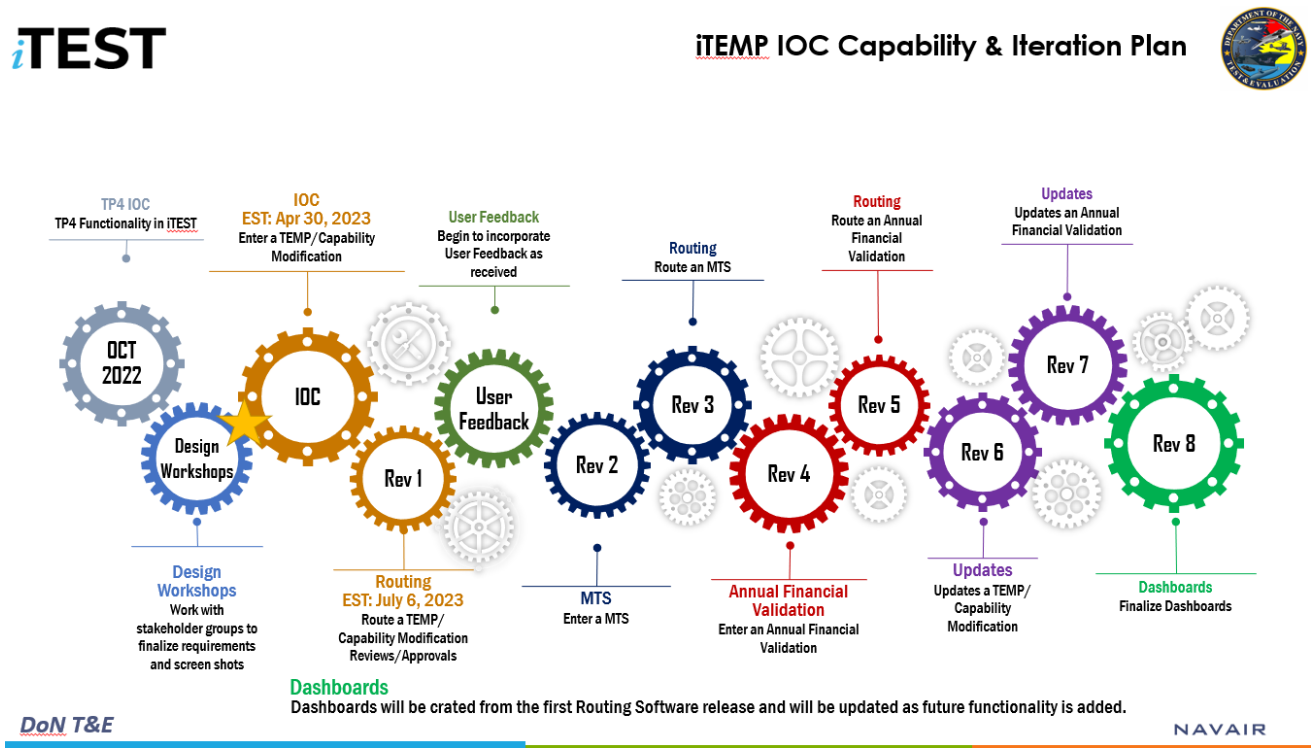
Document Routing & Repository

Interactive tool used to create, route, monitor, and track test documentation (e.g., TPID, PPM, Test Plan, DRs, etc.).

iTrack

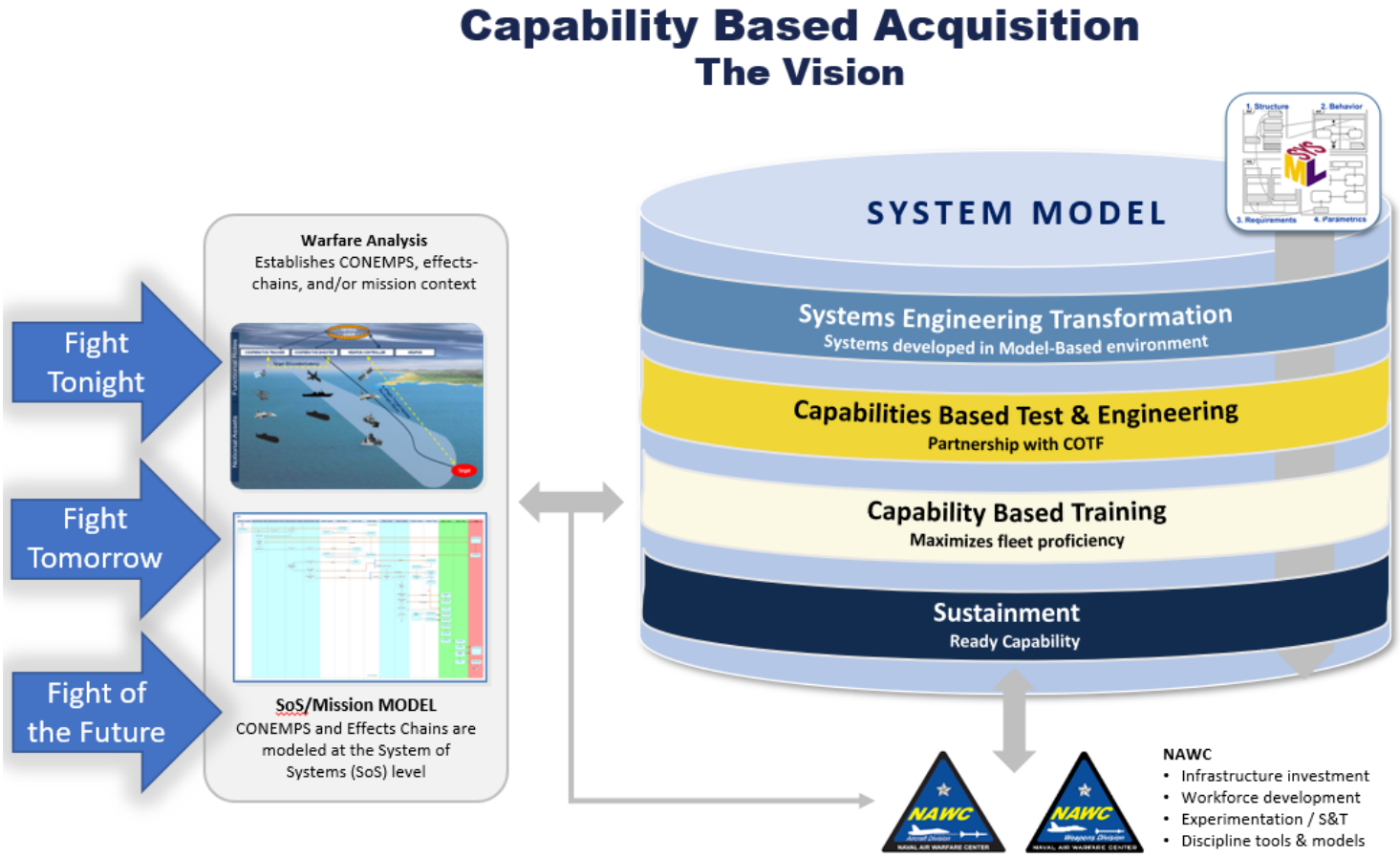
Test Execution Tracking

Interactive tool used to create Test Frameworks (Mission Based Test Design) and track test execution through Test Points, Team Events, Dailies, and Watch Items.



CBTE / MBSE / IDSK Leading Change

NAVAIR's and the DON's approach to Capabilities-Based Test and Evaluation (CBT&E) and its underlying "Test Like We Fight!" mantra, including a mission-based test design process, as part of Capability based acquisition (figure 13) was described. One goal of CBT&E is to unify CT/DT/IT/OT into a single holistic test and evaluation construct – a holistic "T&E Continuum" using DE and MBSE that includes virtually executing T&E and blending it with systems engineering on the left side of the systems engineering "V."



Transforming MBSE Models into Formally Verifiable Language to Support Test and Evaluation as a Continuum

MBSE reduces the effort of developing complex system by improving:

- Requirements
- Traceability
- Code generation
- Design reuse
- Validation and Verification
- Communication

Formal MBSE for Test-as-a-Continuum

The Safety Critical Embedded Software System Challenge

Problem:

- Software increasingly dominates safety and mission critical system development cost
- **80% of issues discovered post unit test**

Inception:

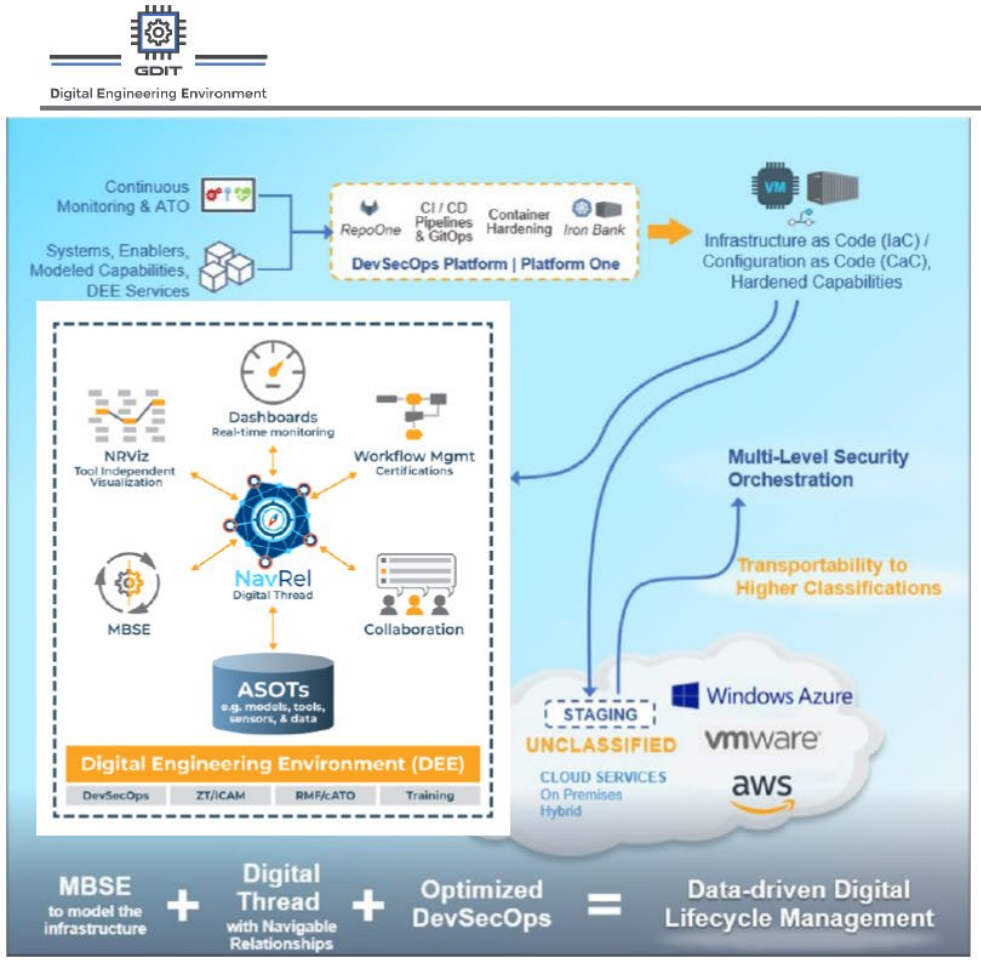
Model-based virtual testbench: joint virtual integration testing and incremental analytical assurance

Solution:

- Technology based on SAE International standard matured into practice through pilot projects and industry initiatives
- Open source research prototyping platform continually enhances analysis, verification, and generation capabilities
- Direct alignment with DoD Digital Engineering Strategy

GDIT Digital Engineering Environment for USAF Sentinel Ground Based Strategic Deterrent Program

DOD's digital engineering strategy promotes the use of digital representations of systems and components and the use of digital artifacts to design and sustain national defense systems.



What GDIT Is Doing for USAF

GDIT is the Systems Integrator for the USAF Sentinel (Ground Based Strategic Deterrent) Digital Engineering Environment (DEE)

The DEE is a living enterprise technical data package that is virtualized, domain transportable and contains the data (data, and applications used to create, edit, & view) associated with the entire weapon system via Authoritative Sources of Truth (ASOT)

To enable users to easily use the ASOT, GDIT built a way to visualize it that enables users to point and click through the ASOT using Navigable Relationships

GDIT DEE is leveraging USAF Fences, Platform One DSOP, Repo1, Registry1, Iron Bank, Big Bang

Incrementally delivering capability - Contract start September 2020, IOC December 2022, FOC December 2023, Transition to the USAF complete August 2024

GDIT and the USAF have unlimited data rights

Lead Developmental Test Organization (LDTO): Digital Engineering with Protected Tactical SATCOM (PTS) Developmental Evaluation Framework Demonstration (Space Systems Command)

The Space Systems Commands' LDTO Developmental Evaluation Framework (DEF) short-term goals, long-term goals, and hurdles for digital engineering.

Short-term goals:

1. Copy critical TEMP inputs into MBSE ecosystem
2. Create System Under Test diagrams in the model for each Test Event
3. Generate Use Cases/test procedures based on CONOPs and trace to system capabilities
4. Trace System under test diagrams to resource allocations
5. Generate entry/exit criteria in model for test event.

Long-term goals:

1. Conduct daily T&E activities using models
2. Utilize model to generate test plans
3. Trace known deficiencies to models instead of the Joint Deficiency Reporting System

Hurdles

- MBSE infrastructure/training is not in place for test and operational community to fully utilize capability
- No current identified standard MBSE tools/architecture/nomenclature across SATCOM systems; may cause interoperability issues across interfaces at the enterprise level
- T&E would need to plan and conduct activities within the model to fully utilize MBSE efficiencies and capabilities
- Model based TEMP approach requires program model architecture to be successful

MBSE in T&E

A GTRI project was discussed that uses an exemplar electronic warfare system to:

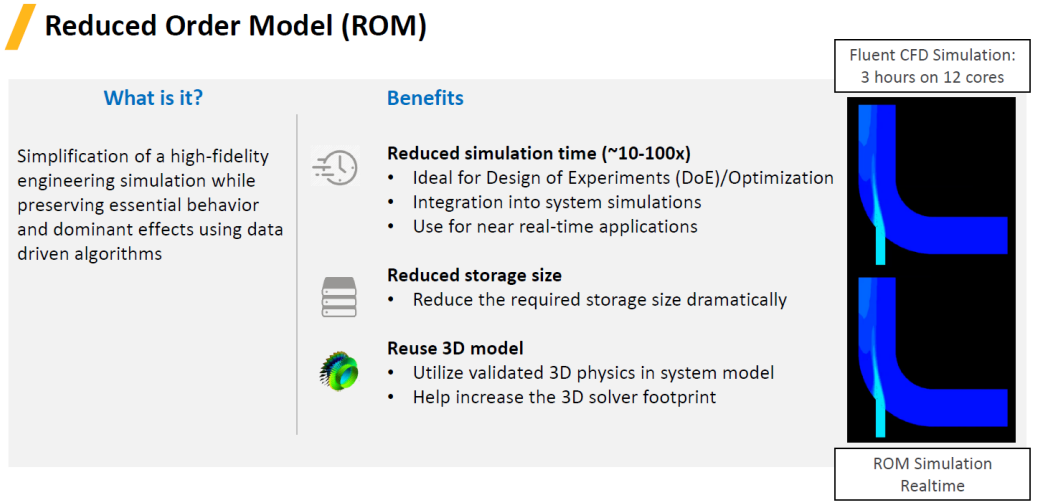
- ✓ Develop a representative set of models linking requirements, design, testing and risk using MBSE
- ✓ Model an example system and demonstrate how test organizations can integrate MBSE models to inform the development of testing documents and plans
- ✓ Develop and implement a risk function this will be linked to the integrated model
- ✓ Include in the risk model a method for linking to program risks

The project also includes modeling and linking test range capabilities which have the following impacts:

1. The model-based test risk function is a new development that gives the program office and the different test organizations better visibility into the different critical aspects of program performance all along the development and testing lifecycle of the program.
2. By integrating testing and model-based systems development we are extending the current methods of Model Based System Engineering (MBSE) in their application to DOD systems.

Digital Engineering Exemplar: Air Force Test Center Targeting Pod

Ansys is providing simulation capabilities and developing workflows to perform virtual testing of infrared search and track (IRST) systems for the Air Force. These solutions are **increasing test coverage and reducing risk** by leveraging simulation to gain information on scenarios that would otherwise be unattainable in the real world. M&S architecture, multiphysics models of aircraft sensors, and ability to generate accurate lightweight, fast-running reduced order models **use a combination of statistical and physics-based machine learning techniques**.



Key Challenges Identified and Recommendations

There are several challenges, both technically and policy-oriented, to finalizing and implementing methods and tools to enable MBTEMPs and other digital acquisition artifacts. We are building a growing digital engineering community for T&E and have discovered several key aspects of the development of sustainable digital engineering and digital acquisition practices and systems across the DOD.

CHALLENGES

Technical challenges:

a. Modeling structures: E.g., MBSE vs. relational database implementations

b. Hosting environments

c. Data standards

d. Enterprise (vice desktop) MBSE solutions.

e. Interoperability requirements of different versions of tools or models.

Policy issues that will need to be decided and agreed upon across a wide range of stakeholders:

a. Who will have authority over the format and the content of the digital artifacts?

b. What will be the best practices for developing and maintaining them?

c. What will be the incremental implementation of the new digital formats?

d. How will legacy and in-flight programs be handled?

RECOMMENDATIONS

1. Key acquisition artifacts including the Test and Evaluation Master Plan (TEMP) must be digitized in a manner that is consistent and compatible across different organizations, as well as new and legacy programs.

2. We should consider an incremental approach to implementing these technologies and methods across new and legacy programs.

3. The development of new tools and processes including the MBTEMP should focus on the addressing the needs of acquisition and test practitioners for us to accelerate the delivery of weapons that work vice imposing new cumbersome requirements.

4. We should prioritize integrating our T&E community and processes with the rest of the DE community.

5. Fully realizing DE's potential for T&E's will be dependent on tight collaboration between the DOD and our industry partners.

Conclusion & Questions

The T&E of these future capabilities will depend upon a data-driven enterprise M&S environment that is integrated into live tests and data feeds and provided as a service to our soldiers, sailors, airmen, guardians, and marines.

Any Questions?

DOT&E's SIPET division—Strategic Initiatives, Policy, and Emerging Technologies—is shaping the T&E of future multi-domain warfighting.