SYM-AM-25-360

Excerpt from the Proceedings

of the

Twenty-Second Annual Acquisition Research Symposium and Innovation Summit

Volume III

The Use of Modeling Systems and Systems of Systems for Acquisition and Test in the DoD

Published: May 5, 2025

Prepared for the Naval Postgraduate School, Monterey, CA 93943.

The research presented in this report was supported by the Acquisition Research Program at the Naval Postgraduate School.

To request defense acquisition research, to become a research sponsor, or to print additional copies of reports, please contact any of the staff listed on the Acquisition Research Program website (www.acquisitionresearch.net).

Acquisition Research Program
Department of Defense Management
Naval Postgraduate School

The Use of Modeling Systems and Systems of Systems for Acquisition and Test in the DoD

Craig Arndt—Principal Research Faculty, Georgia Tech Research Institute. [Craig.Arndt@gtri.gatech.edu]

Sarah Scheithauer—Senior Research Engineering, Georgia Tech Research Institute. [Sarah.Scheithauer@gtri.gatech.edu]

Abstract

The Department of Defense (DoD) acquisition system is in the process of digital transformation. This effort is impacting all aspects, and areas of the acquisition system and also the different systems and process that interface with the acquisition system, including requirements development, test, operations, and threat analysis. Each of these processes have one or more key stakeholders. In each case one or more of these stakeholders generates models in order to facilitate the processes of acquisition (requirements, design, development, test, etc.). The proliferation of models is a good thing form the perspective of digital transformation and the training and cultural transformation of the workforce, however, in order to gain the full benefit from digital engineering and Model Based Systems Engineering these different models need to be coordinated and linked together in meaningful ways.

There are a number of not only different models in use in DoD acquisition and test, but a number of different classes of models which are used for different tasks and implemented using different technologies. Many of these models and modeling systems, were not originally designed to work with the other models that have been developed in other areas of the acquisition process.

The driving for a coordinated approach to developing not only the models effectively but also to prioritize the development of models that easily interface with each other come for the need for programs to be more efficient and the need to deliver capabilities to the war fighter faster. The coordination and integration of different models holds the promise to make significant improvements in these areas.

This paper addresses a number of the issues that arise from the development of a large number of disconnected models and systems. We identify specific areas for technical and for policy development and introduce and specific method for prioritizing work to grow the integration and coordination of these different models and systems.

Keywords: Model Based Systems Engineering, Digital Transformation, Program Management, Lessons Learned

Introduction

The objective of the Defense Acquisition System (DAS) is to support the National Defense Strategy, through the development of a more lethal force based on U.S. technological innovation and a culture of performance that yields a decisive and sustained U.S. military advantage. The acquisition system will be designed to acquire products and services that satisfy user needs with measurable and timely improvements to mission capability, material readiness, and operational support, at a fair and reasonable price. Within the DAS the development and fielding of defense systems is a complex process guided by and wide range of rules and processes. One of the most important processes in the system engineering process. In recent years new technologies have become available to improves the systems engineering process, specifically Model Based Systems Engineering (MBSE).

Digital Transformation

In June 2018 the Department of Defense (DoD) established its expectations for digital transformation in The DoD Digital Engineering Strategy. The strategy outlines five goals aimed at establishing a digital engineering environment for more rapid and effective development and fielding of weapon systems. The goals include using models to inform decision making, establishing an infrastructure to enable the digital engineering methods, and transforming the workforce to adopt digital engineering methods over the acquisition life cycle. Figure 1 was developed by the DoD to help communicate the different elements of the transformation effort. The development and use of standardized models is critical to the success of the transformation and the resulting advantages of digital engineering to the operations of all aspects of the department.

The DoD followed up this strategy with the release of formal guidance via DoD Instruction 5000.97 which ensures that the Director of Operational Test and Evaluation (DOT&E) will utilize digital engineering methods to achieve their test objectives for operational assessment and Live Fire Testing. Also in 2023, DOT&E released their DOT&E Strategy Implementation Plan (I Plan) which includes objectives and key actions to develop digital, or model based Test and Evaluation Master Plans (TEMP) and Integrated Decision Support Keys (IDSK). As recently as December 2024, the department has released an update to DoD Instruction 5000.98 and five DoD manuals further refining the description and use of digital methods for the entire DoD test community (DoDM 5000.96, DoDM 5000.99, DoDM 5000.100, DoDM 5000.101, and DoDM 5000.102).[1]

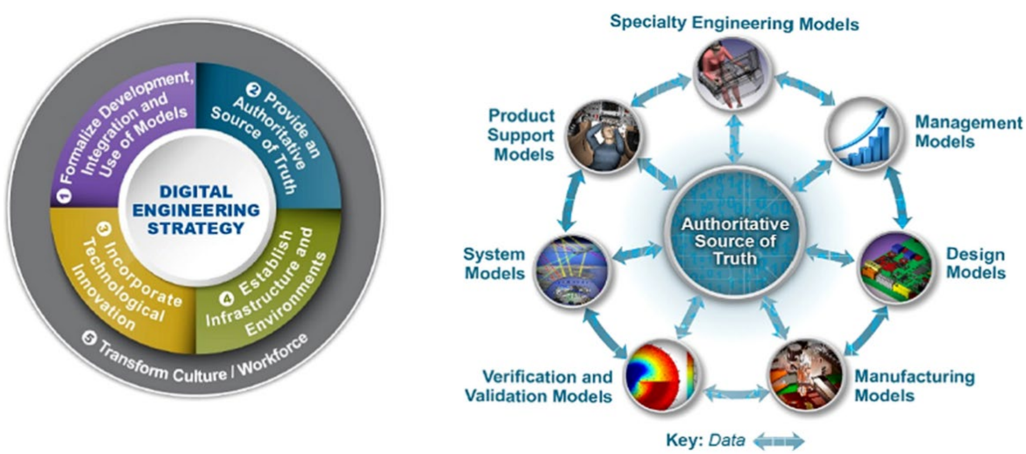

Figure 1. DoD Digital Transformation

Proliferation of Different Systems and Software

The are many different software systems that support digital engineering in use throughout the DoD and the vendor base that develops system for the DoD. When talking about Digital Engineering (DE) and MBSE in the context of the DoD, it is important to remember that both DE and MBSE have been commonly used in other industries for years before the adoption of these technologies by the DoD. As a result, there is a wide range of systems available in the market place for different organizations within the larger DoD ecosphere to get digital engineering infrastructure.

[1] https://www.dote.osd.mil/LinkClick.aspx?fileticket=Dt45nHpTB6A%3d&portalid=97

Background

As program offices and other organizations start to implement MBSE and other digital processes on programs they are discovering a wide range of implementation issues and complications.

Use of MBSE in the Defense Industry

The use of MBSE processes and tools is not new in the engineering industry nor the DoD vendor base. This has great advantages, in that the DoD is not starting from scratch with the implementation of a new technology. However, the fact that MBSE did not start in the DoD also presents significant challenges. These challenges include the fact that the SysML and many Product Lifecycle Management (PLM) systems are designed for commercial manufacturing and production systems, and often don't take into account the intricacies of the DoD acquisition process, such as the types of information and data exchange associated with DoD contracts.

PLM Tools

In industry, PLM is the process of managing the entire life cycle of a product from its inception through the engineering, design, and manufacture, as well as the service and disposal of manufactured products. PLM integrates people, data, processes, and business systems and provides a product information backbone for companies and their extended enterprises. In the case of the government the PLMs are chosen in order to facilitate the management of both government and vendor models needed to manage the development of new systems.

A wide range of software tools have been developed to support a product's life cycle. These include for example the Siemens Teamcenter. Teamcenter is a modern PLM system that connects people and processes, across functional silos, with a digital thread for innovation. The Teamcenter platform is primarily designed to support the design and development of products that subsequently get manufactured. The proliferation of PLMs and the lack of coordination between the different proprietary systems has proven to be a point of difficulty when integration between vendors and different government systems.

Development of MBSE Standards in the DoD

In the long-term however there is a great deal of need for both technical standards and processes. There are a number of different standardizing efforts currently on-going throughout different parts of the DoD and the extended defense industry. However, many of the standardization efforts have not been coordinated industry wide. Other outstanding issues with standards are: 1. The lack of a standard ontology, that is accepted across the industry, and 2. A lack of specific use cases that are used to verify the usability of the standards.

SysML Tools and Versions

In addition to issues with different standards and the lack of standards within the different parts of the industry there is the issue of the fact that the there are several different versions of the primary modeling language for MBSE, SysML. These different versions are not all compatible with each other and different stakeholders and developers use different versions of SysML. This creates considerable expense in conversion and incompatibilities that need to be resolved between organizations that need to transfer or deliver models.

Examples of Other Development

During the past few years there have been significant development programs created to standardize many key parts of the modeling process as it directly applies to DoD acquisition. Some of the more important activities are referenced below.

Arizona Ontology

In an attempt to address the issue of significant differences in both terminology and definitions of terms, but more importantly a differences in architectures, the University of Arizona developed a set of ontologies. These ontologies fill an important need for consistent definitions and architectures. Figure 2 shows how the ontology can be integrated with other acquisition related models. In this case the ontology is integrated with a Model Based TEMP.

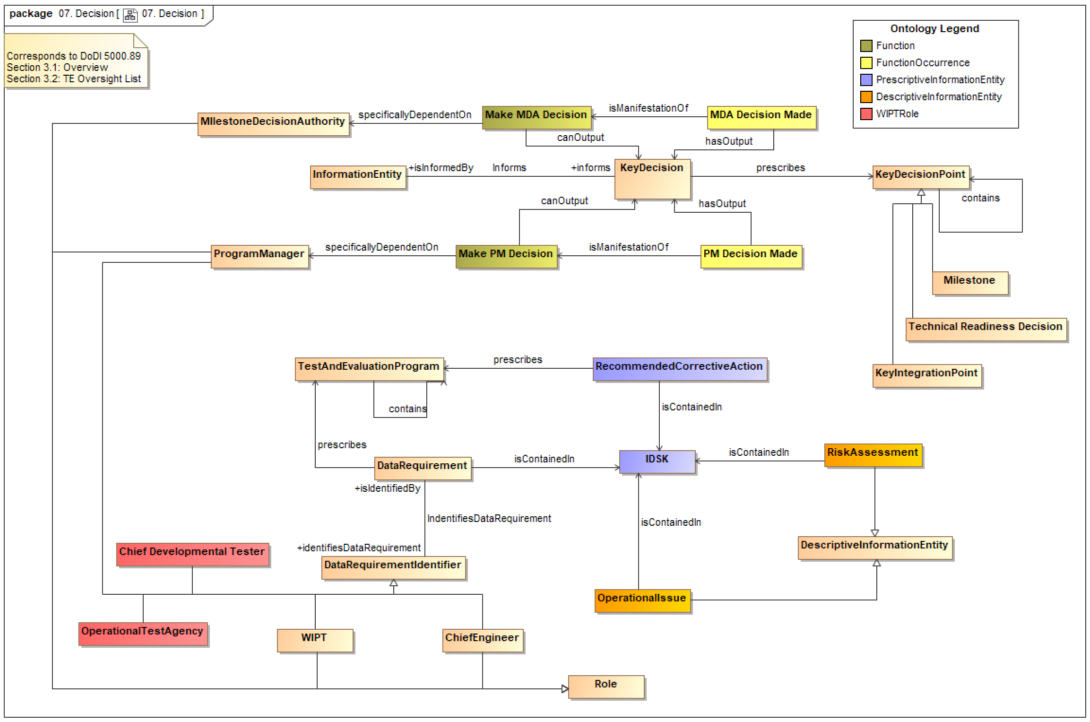

Figure 2. The Arizona Ontology as Implemented in SysML

Johns Hopkins University Meta Model

As a part of a project to improve the ability of different models to pass data and otherwise communicate Johns Hopkins University (JHU) teamed with the DoD to develop a Meta Model of MBSE process within the DoD acquisition process. Figure 3 shows a part of the Meta Model that will be used by the DoD to develop interface to allow future integration of models.

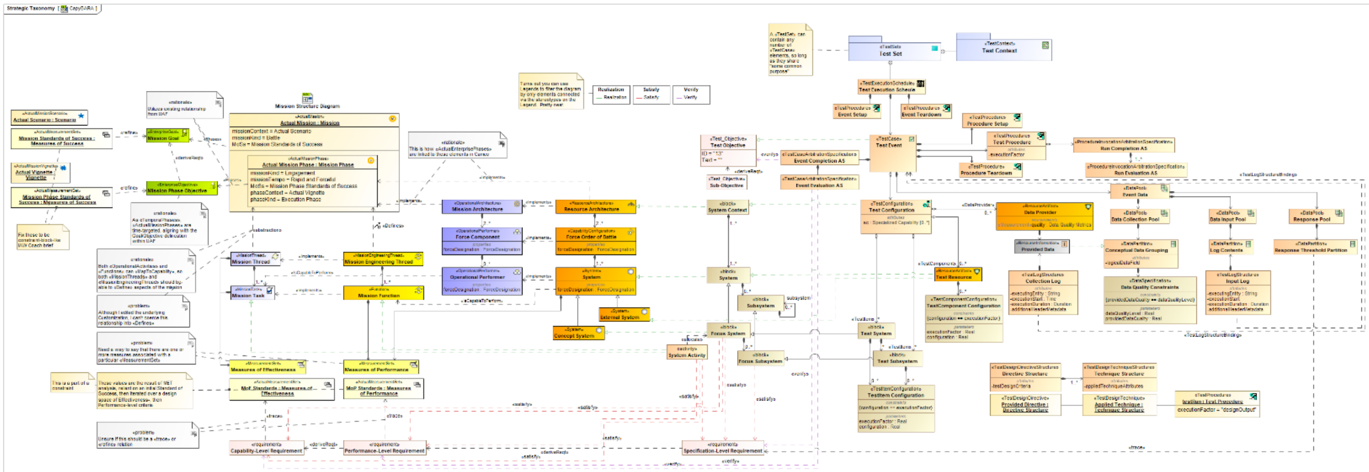

Figure 3. JHU Meta Model

Integrated Decision Support Key Architecture

The Integrated Decision Support Key (IDSK) was developed in order link acquisition decision making to the sources of data needed to make these decisions. To make the IDSK compatible with MBSE, DOT&E teamed with Georgia Tech to development the Model Based IDSK Reference Architecture. In Anyanhun and Arndt (2024) an MB-IDSK reference architecture (MB-IDSK RA) was proposed and developed to support digital transformation efforts of DOT&E. The motivation behind defining a MB-IDSK RA was based on the premise that an architecture should reflect the organization of the owning enterprise (CAS, 2022). Specifically, the MB-IDSK RA represents an essential tool to facilitate communication and alignment efforts of current and future IDSK architectures. Figure 4 depicts the IDSK architecture strategy as adapted from the DoD Comprehensive Architecture Strategy.

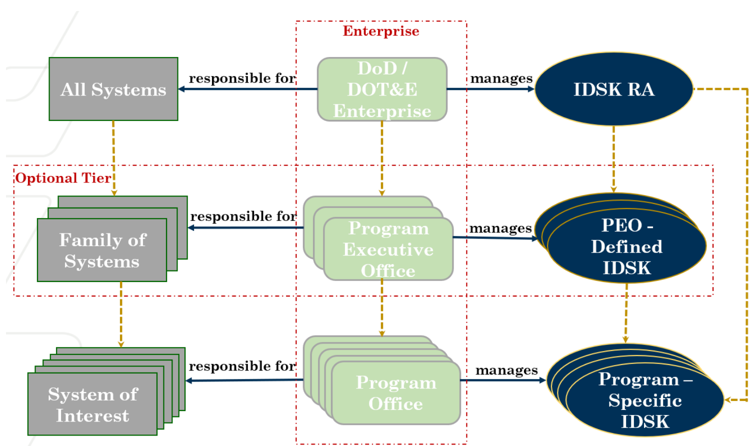

Figure 4. IDSK RA Architecture Strategy Adapted from Figure 1 of the DoD CAS (CAS, 2022)

The MB-IDSK RA is developed to demonstrate and provide guidance on how the T&E enterprise and acquisition programs implementing digital engineering could leverage existing digital models created during the various acquisition phases as real-time data sources to inform key program decisions and improve decision outcomes.

Model-Based TEMP Reference Architecture

The Test and Evaluation Master Plan or TEMP is a foundational document or artifact. The Model-Based Test and Evaluation Master Plan Reference Architecture (MB-TEMP RA) Model was developed using a domain-based approach. The MB-TEMP RA in an example of how more than one different model can be tied together for a common purpose architecturally. These models linked together within the Model Based TEMP include a Model-Based IDSK Reference Architectures, mission models, test range and facility models, test models, requirements models, system models, and the Test and Evaluation (T&E) Reference Metadata Model (2011).[2] An example of the architectural views of the MB-TEMP RA is portrayed in Figure 5.

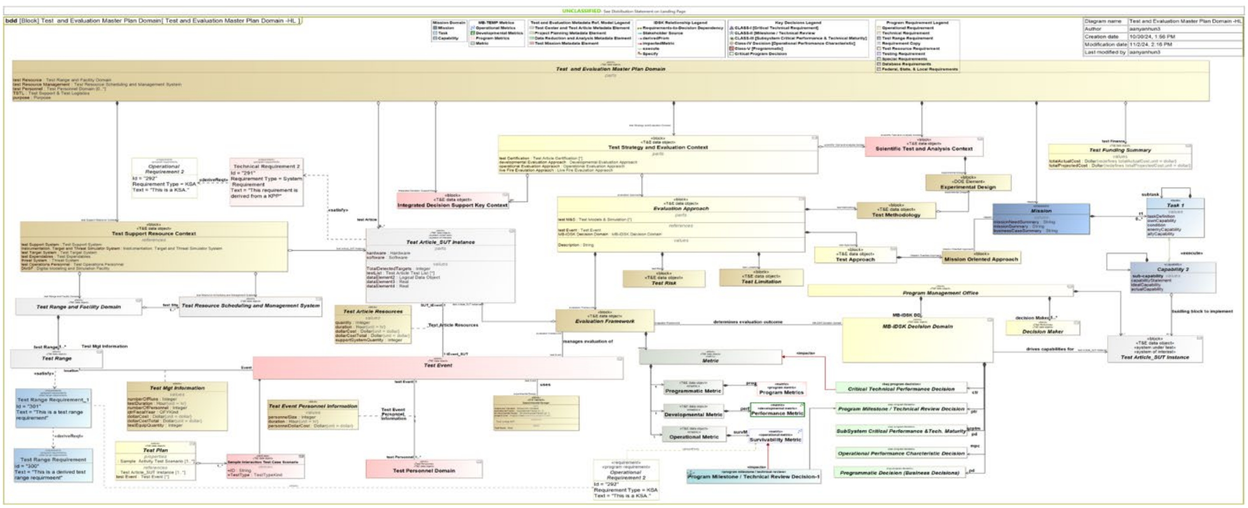

Figure 5. TEMP Domain View of the MB-TEMP RA

Figure 5 shows the TEMP Domain view of the MB-TEMP RA provides crucial insights into the top-level composition of the TEMP domain. The RA view links together elements defined within the TEMP model and elements already defined in digital models that exist within a program's digital engineering ecosystem. These digital models include a *program office model, requirements model, system model, SUT model, and test range models*.

Need

The DoD digital transformation gave a significant amount of guidance on performing the digital transformation. Figure 1 shows the top level of guidance in the DoD level transformation. However, this guidance does not provide guidance on the functional elements of the operations of digital acquisition.

In order to better understand what is needed for an end-to-end life cycle digital acquisition program we need to define a digital thread that looks at the different elements of both the acquisition program and the models that are involved on executing that program. This digital thread can be defined across the life cycle and also across the different models that will create a link between the models to allow for visibility of the data created across the different models to inform the other models and critical decisions that need to be made with regards to the system development. As can be seen in Figure 6, there are a wide range of different models created in the development of a new system. When the integrated digital thread is developed linking all of

[2] https://apps.dtic.mil/sti/tr/pdf/ADA640532.pdf

the different models together the data needed to make critical decisions more available to decision makers.

In commercial industry the process is much easier, due to one organization controlling the development of most if not all of the different models. This however becomes much more difficult in the case of the DoD, where the different models are developed by different organizations within the government and outside of the government, and no one has control over all aspects of the total set of models that need to be integrated together.

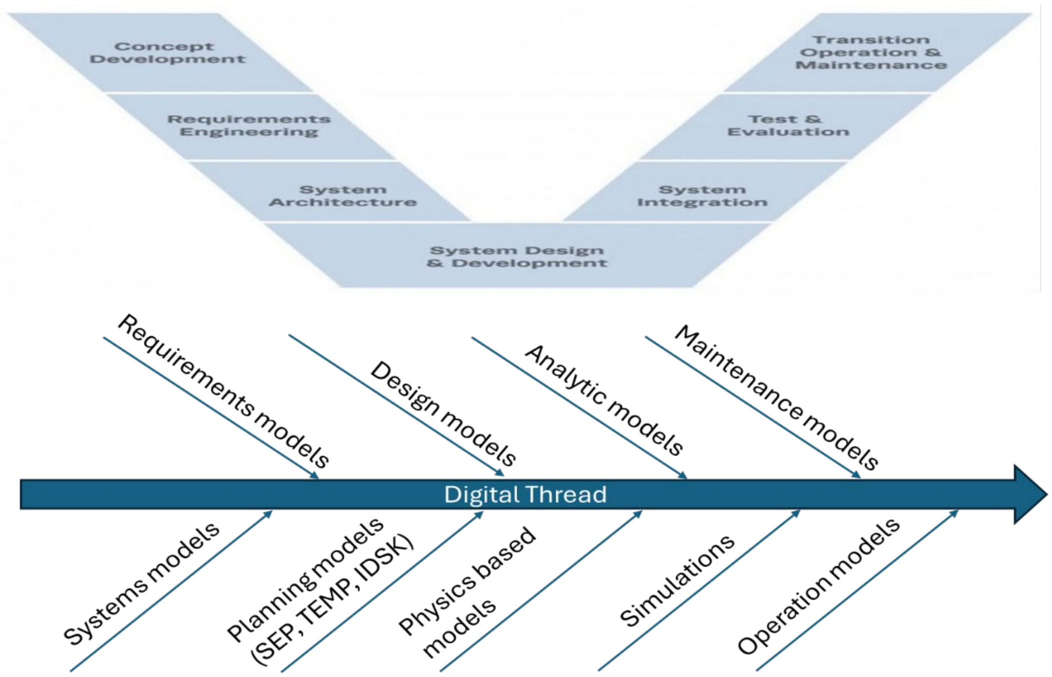

Figure 6. Digital Thread Across the Life Cycle

Progress in Many Places

The DoD community has been development many different digital tools and solutions for the acquisition process. The community involved in these developments has included, vendors, tool makers, government organizations, FFRDC's, and universities.

Communities of Interest

In the development of DE tools and MBSE tools several important organizations have been instrumental in the development of underlying constructs, and principals. INCOSE and the Object Management Group, or OMG, jointly chartered the OMG Systems Engineering Domain Special Interest Group or SE DSIG to create the Unified Modeling Language (UML) for Systems Engineering Request for Proposal which was completed in 2003. The development of the SysML modeling language is documented in Figure 7.[3]

[3] SysML History, https://www.incose.org/

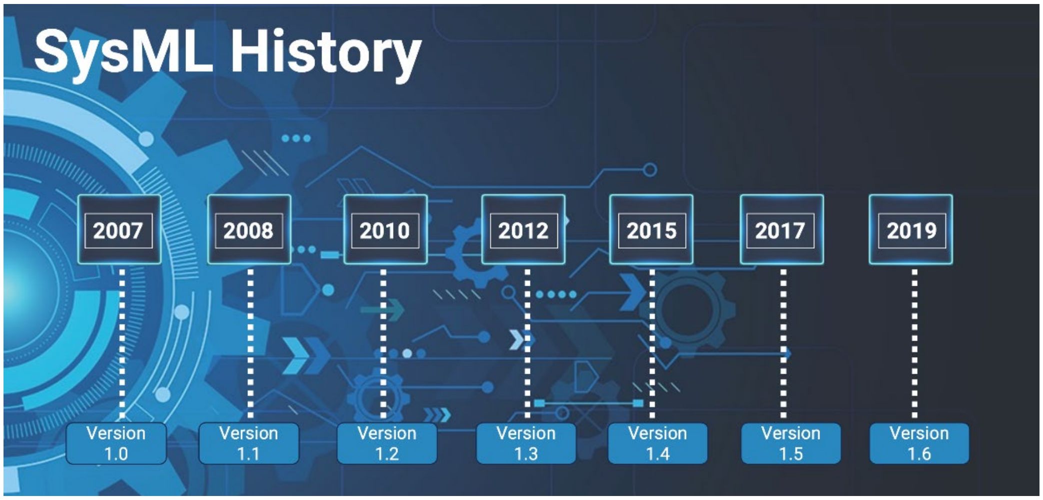

Figure 7. History of the SysML Language

DoD Policy Shops

In addition to industry groups, the leadership of the DoD have been instrumental in the development of requirements for the digital engineering tools that we use today. Several specific efforts have been forwarded by specific part of the DoD, and the Office of the Secretary of Defense (OSD).

DOT&E

The leadership of the DOT&E has done a great deal of work to define important acquisition artifacts in digital formats including the MB-IDSK and the MB-TEMP. Other groups, including the Office of the Undersecretary of Defense for Research and Development, Research and Engineering (OUSD[R&E]) have sponsored work in defining meta models of the acquisition process and structured data exchange metrics to accommodate the larger multi model environment.

Specific Program Offices

In addition, a number of forward-thinking program offices have chosen to be pathfinders in the development and implementation of digital engineering within their programs. These pathfinder programs have developed a number of key guidelines for the development of practical aspects of the MBSE within the programs. These programs have also contributed significantly to lessons learned.

Governance Issues

Governance can many different forms. When we talk about the governance of models, we look at sources for the different aspects of the governance: 1. direction about the structure of the models, 2. the content of the models, and 3. the interfaces and use of the other models to support the primary system models. At the highest-level international standards bodies (International Standards Organization [ISO] and Internation Council on Systems Engineering [INCOSE]), maintain top level standards for the SysML language. In addition to that, there needs to be standards that are specific to the defense industry and DoD acquisition.

DoD acquisition programs get the majority of the governance for DoD Instructions, and other policy documents. Traditional additional governance has been provided by panning document like the Acquisition Strategy, the TEMP, and the modeling and simulation plan, for the program. At this point additional governance is needed to deal with the complexities of managing the models needed to run a complex defense acquisition. One of the biggest complications in developing good comprehensive governance is the fact that many of the supporting models that are needed to develop the full life cycle of the program are not controlled by the program office or even the same government agency. Some governance can be provided to the vendors, though the RFP, and subsequently thought the contract, but outside government organizations that provide data and models that are needed to support the program and span the life cycle, including, threat, requirements, test, and configuration models. It is clear that comprehensive governance needs to be provided all stakeholders in order to ensure that content and interfaces needed to manage programs can be generated effectively.

Experience on real programs has shown us that the development of governance early is critical, because it needs to be provided to all the key stockholders before they develop their models.

Ongoing Challenges

With all of the work and advancements in digital engineering and MBSE, there still a number of major challenges that need to be both better understood and overcome in order to fully realize the potential of DE and MBSE.

Integration Across the Life Cycle

There are many different classes of models, and different models, that will need to be integrated, in order to make an integrated system of models. There are many specific challenges to integrating these different models. The integration of the different models will require dedicated interfaces.

The power of MBSE is multiplied when data can be shared across time and across all of the different models that are developed by different organizations involved in the development, fielding and operations of the system. To achieve a greater level of integration of the different models across time and models, will require: 1. better documentation of data formats and structure in all of the relevant models, 2. better version control for supporting software systems and languages, and 3. some degree of coordination between the developers of the different models.

Return on Investment and Measures of Effectiveness

Currently there are a wide number of possible levels of implementation of MBSE within specific programs and different parts of the development life cycle. However, there is a limited amount of time available to conduct meaningful return on investment (ROI). In order develop these systems in a meaningful way, we will need to effectively develop metrics to evaluate progress.

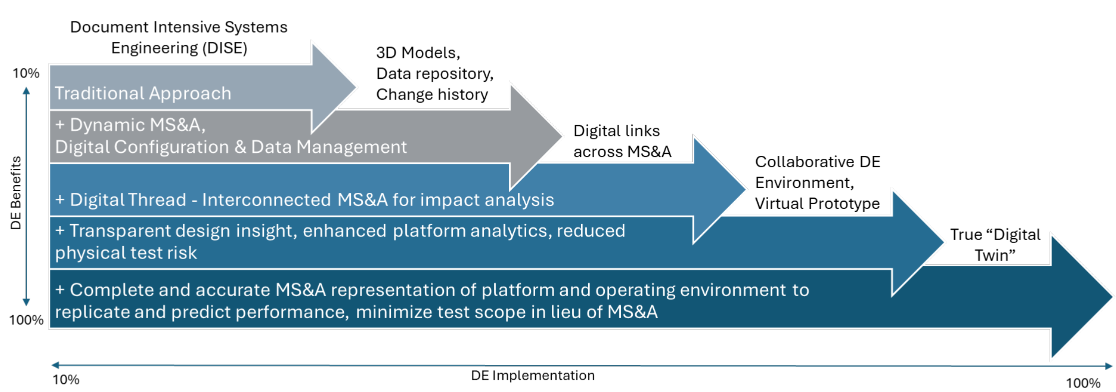

Figure 8. A Structured Approach to Different Levels of Implementation

However, there is a lack of tools and methods available in order to make good decisions on the level of implementation based on the return on investment for specific programs and meaningful metrics for the return in investment. There are any number of possible ways to implement digital engineering into any given program. Figure 8 shows the incremental approach that is being look at by many DoD programs. This allows programs to select the pathway to digital implementation that make the most sense given their current state and the resources they are willing to expended to make the conversion to digital engineering.

This is however only the first step in implementing a fully digital life cycle for any given system. The issue remains that many of the vendor systems do not match systems and processes adopted by the program offices. The adjacent and supporting processes and models that support and / or feed into the program offices models and process are not coordinated or compatible with the program offices' systems. This lack of coordination continues to create significant issues for the program offices.

Conclusions

To say that we need to better integrate the different models involved in the acquisition process, is true, but does not tell the complete story of what is needed to facilitate realizing the benefits of DE. The full realization of an integrated digital modeling environment will need to be achieved incrementally for a wide range of reasons that we have discussed here. The difficulties the DoD is having with digital transformation are both technical and also programmatic. Several key things that we have discovered about these issues are summarized below. One of the first things that needs to be done is to ensure that we are learning about incompatibilities and technology disconnects before it is far too late in the development programs. After a contract is awarded and on a fixed timeline it is far too late to discover incompatibilities.

Ideally, the DoD's digital integration system will be transparent across different models and systems. There have been a number of different technical issues that have prevented this from happening to the degree that could be possible. Some of their technical courses have included differences in ontologies, PLMs and other non-modeling IT resources, and infrastructure.

Non-technical issues include programmatic / contracting issues. The introduction of DE has proven to be a challenge to all aspects of the acquisition process. Contracting for digital deliverables requires a number of significant differences in the contracting process, including new Digital Data item Descriptions (DiDs). The acquisition community and the Defense Acquisition University (DAU) and others have been collecting lessons learned from a wide range of sources. These efforts need to continue and be expanded, shared, and collated.

Recommendation / Path forward

There is a lot that we can, should, and need do to accelerate the digital transformation and implementation of MBSE. The DoD has chosen to adopt DE practices within the context of the DoD priority to accelerate the delivery of systems to the field. Below are several key next steps that can be done to accelerate the DoD's ROI in terms of accelerating the acquisition.

Working More and Better with Vendors

As we have seen in different parts of this paper the interactions between the program offices and vendors can be very complex, difficult, and time consuming. Considerable ROI can be achieved by creating transparent connections between the government acquisition organizations and the different vendors developing programs.

More Standards and Reference Architectures

In order to guide the development and integration of different digital engineering, and more partially specific standards and methods (similar to IEEE/ISO/IEC 15288-2015) that will allow program offices to quicky and easily implement DE and MBSE process. These processes need to be structured into very specific and definable pathways for specific tasks and digital threads that lead to improved acquisition outcomes.

More Pervasive Training of All Parts of the Acquisition Work Force

Every major plan for digital transformation that the DoD and other organizations has strongly recommended training for the DoD workforces in DE and MBSE. Most of these recommendations have focused on the engineering teams that will be working with the vendors. To date, the DoD's efforts in training have not been as effective or as wide spread as they would have liked. In addition, focusing on the engineering teams has not advanced the goals of developing a full digital program. We recommend that the DoD increase the DE and MBSE training and expanded it to program management and contracting areas.

Reduction in Redundant Activities

Over the past few years there has been significant research and development in the area of applications of both DE and MBSE conducted in order to advance these areas. However, at some point this research and development becomes redundant when efforts are not coordinated. We have gotten to that point. In addition, the different research and development efforts are in many cases incompatible. In order to maximize the effectiveness of different research and development the efforts will need to be coordinated and reconciled based on guidance for the government.

References

Anyanhum, A., & Arndt, C. (2024, September). *The use of AI and systems engineering processes in and for testing of AI-based systems*. SERC AI4SE/SE4AI Workshop.

Army Aviation and Missile Command Fort Eustis VA. (2022). *Comprehensive architecture strategy (CAS)*. https://apps.dtic.mil/sti/pdfs/AD1185001.pdf

Arndt, C., Anyanhun, A., & Werner, J. S. (2023).*Shifting left: Opportunities to reduce defense acquisition cycle time by fully integrating test and evaluation in model based systems engineering*. Acquisition Research Program.

Beers, S. M., Hutchison, S., & Mosser-Kerner, D. (2013). Developmental test evaluation framework: Focus on evaluation and analysis for acquisition Success. *Phalanx*, *46*(3), 36–39.

Beers, S. M. (2023). *Integrated decision support key (IDSK) for capability evaluation-informed MDO decision-making*. ITEA MDO Workshop, July 2022.

Collins, C., & Beers, S. M. (2021, December). *Mission engineering, capability evaluation & digital engineering informing DoD technology, prototyping and acquisition decision*. NDIA S&ME conference.

Director, Operational Test and Evaluation. (2017). *Test and evaluation master plan (TEMP) guidebook version 3.1*.

DoD. (2020). *DoD instruction 5000.89: Test and evaluation*.

DOT&E. (2022). *Office of the Director, Operational Test and Evaluation strategy update—Strategic pillars*.

https://www.dote.osd.mil/Portals/97/pub/reports/FINAL%20DOTE%202022%20Strategy%20Update%2020220613.pdf?ver=KFakGPPKqYiEBEq3UqY9lA%3d%3d

Executive Services Directorate. (2020). *DoD instruction 5000.89*. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500089p.PDF

Gregory, J., & Salado, A. (2024). An ontology-based digital test and evaluation master plan (dTEMP) compliant with DoD policy. *Systems Engineering.*

Gregory, J., & Salado, A. (2024). dTEMP: From digitizing to modeling the test and evaluation master plan. *Naval Engineering Journal, 136*(1), 134–146.

Gregory, J.& Salado, A. (2024). Towards a systems engineering ontology stack. In *INCOSE International Symposium*.

IEEE SA. (n.d.). IEEE/ISO/IEC 15288-2015: ISO/IEC/IEEE international standard—Systems and software engineering—System life cycle process. https://standards.ieee.org/ieee/15288/5673/

ISO/IEC/IEEE. (2022). *Systems and software engineering—Architecture description* (SO/IEC/IEEE 42010:2022(en)).

Muller, G,. & Hole, E. (2007). *Reference architectures: Why, what and how* [White paper]. Embedded Systems Institute and Stevens Institute of Technology.

OpenCAESAR. (2024). *Ontological modeling language 2.0.0*. [https://www.opencaesar.io/oml/.

Range Commanders Council. (2011). *Test and evaluation metadata reference model*.

Werner, J. S., & Arndt, C. (2023). *Development of digital engineering artifacts in support of MBSE based test planning, execution, and acquisition decision making*. Acquisition Research Program.

Acquisition Research Program
Department of Defense Management
Naval Postgraduate School
555 Dyer Road, Ingersoll Hall
Monterey, CA 93943

www.acquisitionresearch.net