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Acquisition with Digital Engineering

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Table of Contents

List of Figures

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Acronyms and Abbreviations

AAF	Adaptive Acquisition Framework
ACAT	Acquisition Category
AIRC	Acquisition Innovation Research Center
ASOT	Authoritative Sources of Truth
CDRL	Contract Data Requirements List
CIO	Chief Information Officer
CIP	Critical Intelligence Parameters
DAS	Defense Acquisition System
DAU	Defense Acquisition University
DE	Digital Engineering
DEAE	Digital Engineering and Acquisition Ecosystem
DEE	Digital Engineering Environment
DEIP	Digital Engineering Implementation Plan
DFARS	Defense Federal Acquisition Regulation Supplement
DID	Data Item Description
DoD	Department of Defense
DoDI	DoD Instruction
ERI	Exemplar Reference Implementation
EVMS	Earned Value Management System
FAR	Federal Acquisition Regulation
HITL	Hardware in the Loop
IMD	Intelligence Mission Data
IMP	Integrated Master Plan
IMS	Integrated Master Schedule
ISTAAF	Intelligence Support to the Adaptive Acquisition Framework
KPP	Key Performance Parameter
LCSP	Life Cycle Sustainment Plan
LMDP	Life-cycle Mission Data Plan
LSE	Lead Systems Engineer
MCA	Major Capability Acquisition
MDAP	Major Defense Acquisition Program
MTA	Middle Tier Acquisition
NAVAIR	Naval Air Systems Command

OUSD(A&S)	Office of the Under Secretary of Defense for Acquisition and Sustainment
OUSD(R&E)	Office of the Under Secretary of Defense for Research and Engineering
PM	Program Manager
PSM	Product Support Management
R&M	Reliability and Maintainability
SEMod	SE Modernization
SEMP	Systems Engineering Management Plan
SEP	Systems Engineering Plan
SERC	Systems Engineering Research Center
SOW	Statement of Work
SoS	System of Systems
T&E	Test and Evaluation
TEMP	Test & Evaluation Master Plan
USD(A&S)	Under Secretary of Defense for Acquisition and Sustainment
USD(R&E)	Under Secretary of Defense for Research and Engineering
V&V	Validation and Verification

Executive Summary

Digital engineering is as fundamental a paradigm shift as the pathways in the Adaptive Acquisition Framework (AAF); affecting all pathways and supporting functions and enabling broad benefits in the transformation to Digital Acquisition.

Digital engineering implementation and benefits involve and affect all acquisition functions—not just systems engineering.

In June 2018, the Under Secretary of Defense for Research and Engineering published the Department of Defense (DoD) Digital Engineering (DE) Strategy.[1] Since then, the DoD's engineering and technical communities have acknowledged and are adopting DE as a transformative, value-added approach to improving weapon system development, capability integration, testing, and sustainment. However, **for successful DE implementation in acquisition and sustainment, the broader benefits and the realization of complete Digital Acquisition, must involve *all acquisition functions*—not just technical ones.**

In other words, acquisition with DE support, a.k.a. DE-enabled acquisition, cannot succeed as an engineering initiative pushed by engineers. It **must be pulled into acquisition and sustainment by acquisition and sustainment functionals and fully integrated across all of their activities, including those that are not seen as technical**. This report explores some of the methods, processes, and tools in the acquisition and sustainment functions beyond engineering that need to implement DE and realize its benefits, ultimately to our warfighters and taxpayers.[2]

DE pilot efforts have demonstrated that it is fully possible to conduct government acquisition planning, contractor source selection, and engineering and manufacturing development in a shared Digital Engineering and Acquisition Ecosystem (DEAE). This requires government management and provisioning of program data and models as appropriate authoritative sources of truth (ASOT) and a collaborative digital environment with defined government and contractor access, workflows, and digital artifact "views". A concurrent research task conducted by the Systems Engineering Research Center (SERC)/Acquisition Innovation Research Center (AIRC) and Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)) found a significant number of pain points that are creating a slow adoption of DE in DoD program offices. These include a lack of the ways and means to drive adoption; a lack of fully integrated DEAE reference implementations; lack of modernized engineering and technical management processes; and poor understanding of the value and benefit of DE across all acquisition and non-engineering functions.

[1] 2018-Digital-Engineering-Strategy (cto.mil)

[2] The current seven managed acquisition workforce functional areas are Auditing, Business Financial Management/Cost Estimating, Contracting, Engineering and Technical Management, Life Cycle Logistics, Program Management, and Test and Evaluation (from DAU Back-to-Basics, https://www.dau.edu/back-to-basics).

Each of the current seven managed acquisition workforce areas, at a minimum, have a role to play in the DE transformation of acquisition and sustainment practices, to benefit from the continuum of digital artifact availability and use. Below are some of the new or modernized acquisition and sustainment processes that are recommended to be addressed in the digital transformation of the Defense Acquisition System (DAS), as an example of the scale and need beginning with implementation of DE within the DAS:

- *Life Cycle Logistics:* ensuring that authoritative data and models and their use are included in the system Life Cycle Sustainment Plan (LCSP), lifecycle cost analyses, and the government/contractor product support analyses and strategy, and made available to the logistics and supply domain.
- *Engineering and Technical Management:* developing the collective ASOT and associated DEAE per the lifecycle management plan, as documented in the program Digital Engineering Implementation Plan (DEIP), as a main part of the Systems Engineering Plan (SEP).
- *Program Management:* planning and budgeting for data and models across the full lifecycle, defining and managing program office requirements that are consistent with the use and expected benefits of DE, selecting acquisition pathways and defining appropriate DE model-based review processes, staffing the program office with sufficient digitally skilled program office personnel in appropriate functions, defining data exchange requirements for data and models across the spectrum of their use, defining and tracking DE activities in earned value management systems (EVMS) as well as Integrated Master Plan (IMP) and Integrated Master Schedule (IMS), defining a DE measurement plan and inspecting program digital artifacts delivery for completeness and consistency.
- *Test and Evaluation:* defining and planning the verification and validation (V&V) requirements and operational assessment with and of models, using data from live events to update models and the collective ASOT, capturing appropriate digital test artifacts in the ASOT, developing the digital Test and Evaluation Master Plan (TEMP).
- *Business Financial Management/Cost Estimating:* DE data and models integrated into cost modeling, updating cost estimation models to reflect the relative resource (time, budget, and personnel) costs, cost avoidance and potential savings of DE in the complete, executed lifecycle of a system, including but not limited to development, production, and sustainment.
- *Contracting:* incorporating DE processes, data and model exchanges, and digital review processes into the Statement of Work (SOW), defining data and model exchange and delivery requirements, defining program DEAE requirements.
- *Auditing:* ensuring appropriate management of program digital artifacts so curation is possible.

Consistent with the Federal Acquisition Regulation (FAR) and the Defense Federal Acquisition Regulation Supplement (DFARS), the digital artifacts that result from DE implementation can be viewed legitimately as *technical data* and *computer software*. However, there are a few issues in simply specifying in a contract the delivery of these artifacts. Taking delivery of these artifacts versus their actual use are very different in terms of value and detail necessary in specification. **In other words, viewing DE as a set of digitized artifacts using the same acquisition and sustainment intent**

historically applied to *paper* and *document* artifacts may not ensure the quality and information exchange needed, thus defeating the value of a DE-enabled DAS, on the journey to digital transformation of the DAS. The programmatic value of DE and associated artifacts come from the government and contractor aligned teams conducting their respective development, analysis, decision making, and certification activities from a common set of data and models (known collectively as the ASOT), continuously, in an appropriately shared government and contractor DEAE. These data and models must be managed and curated in the associated DEAE across the full lifecycle of the weapon system, appropriate for the subsequent acquisition activities necessary to bring the product to realization. This could include Needs Statements, Mission Engineering, Requirements, Budgeting, Acquisition, Test, Operation, Sustainment, and Disposal phases.

The policy basis for DE-enabled acquisition must fully communicate the *intent and benefits* of DE methods and results from computational activities, to be used in other non-technical activities. Engineering activities (supported by DE) in policy remain overly focused within the Major Capability Acquisition (MCA) pathway. **DE-enabled activities should be fundamental to any acquisition function in any Adaptive Acquisition Pathway**. As with the pathways in general, it is not intuitive to move from DE support from MCA to any other pathway. It should be articulated for non-MCA-focused staff, how to transfer fundamental DE-enabled acquisition process knowledge from MCA to their pathways of choice.

The acquisition and sustainment communities have an opportunity to shape DE methods and reap benefits of DE-enabled acquisition and sustainment through active engagement and demand signals. Without a clear demand signal from the acquisition and sustainment user community, it is impossible for the DE practitioners to know how DE will be used by acquisition and sustainment, and how to prioritize the order of method development to benefit acquisition and sustainment. The *who* is clearly the acquisition and sustainment communities writ large; however, the *what*, *when*, *where*, and *how* needs to be further developed by the acquisition and sustainment functional communities along with their demand signals.

This research task included a review of DoD issuances and other available guidance for DE-related contract artifacts and flows, as well as general acquisition policy and guidance. Most of the available policy and guidance reflects the impact of DE on contracting in the regulatory domain of technical data and models, or as sets of recommended engineering processes. There is a general lack of related guidance that acknowledges the much broader changes that should be realized in fully digital processes and workflows. These can be characterized as (i) a general “shift left” to conduct program definition, development, and test activities earlier—some possibly even into government pre-acquisition activities, (ii) an exchange of digital development artifacts into manufacturing (commonly known as “digital thread”), and (iii) long-term lifecycle maintenance of digital models and environments (“digital twins”, et al) to inform and improve logistics, sustainment, and even feedback into requirements and mission engineering decision making for related products.

In conclusion, the DoD is at an intersection in its ability to utilize industry-accepted, standard DE practices to improve defense acquisition and sustainment. All acquisition and sustainment functions—not just engineering and technical management disciplines—need to engage through a shared demand signal to the DE practitioner community. This report lays out this fundamental perspective and identifies several recommended areas of activity, summarized in the next section.

1. Research Objectives

The original objective of this research was to define initial recommendations for a standardized process flow and associated acquisition artifacts that would be used to implement a DE flow of data and models in any Acquisition Pathway. However, due to unforeseen challenges with obtaining necessary documentation, the research team lightened the standardized process flow direction, in order to gain a better picture of digital transformation challenges of acquisition and sustainment.

Digital Engineering as a technical and management approach is "an integrated digital approach that uses authoritative sources of systems' data and models, along with other information, as a continuum across disciplines to support life cycle activities from concept through disposal."[3] Today the acquisition and sustainment communities are in the initial stages of their DE transformation and need additional research and guidance to define the workflows and processes to contract for, use, and sustain fully digital model-based artifacts and the associated digital environments. The acquisition and sustainment communities, from practitioners to decision makers, based on current policy, guidance, and observed practice, still retain a document-centric view of engineering technical and management data, as periodically delivered artifacts. The benefit of DE application comes from government/contractor collaboration around and through models (vs. document generation and review) in environments that continuously allow the use of models and associated data to generate results from, and for computational analysis and review. Program offices do not have adequate guidance on how to enable effective use of DE methods, tools and associated products when making materiel development, or sustainment decisions anywhere in a system lifecycle.

Additionally, the vision in the DoD Data Strategy (conceived separately from DE) of "a data-centric organization that uses data at speed and scale for operational advantage and increased efficiency"[4] is not yet sufficiently captured into engineering or acquisition and sustainment policy and guidance. Program offices need additional guidance in various areas that can effectively define their workflow and enable data-supported decisions within the engineering, acquisition, and sustainment activities.

Initial example acquisition artifacts are being exchanged through various pilot projects, and in a small set of acquisition programs of record, but these are not the norm. There are statutory requirements for delivery of technical data and computer software. These easily support exchange of data and models between government and contractor[5], but not the widespread use needed for the continuum of product lifecycle operations. Additionally, some statutory requirements generally echo existing standards for written documents which are static entities and do not meet the goal of the DoD Digital Engineering Strategy – to collaborate around, with, and through data and models.[6]

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[3] Office of the Deputy Assistant Secretary of Defense (Systems Engineering) [ODASD (SE), "DAU Glossary: Digital Engineering," Defense Acquisition University (DAU), 2017.

[4] Department of Defense Data Strategy, September 2020.

[5] Defense Federal Acquisition Regulation Supplement (DFARS), Part 227, subparts 227.71 and 227.72.

[6] Department of Defense Digital Engineering Strategy, June 2018.

Examples of acquisition guidance include the NASA Digital Engineering Acquisition Framework Handbook,[7] and the Software Engineering Institute (SEI) "Guidance for Tailoring DoD Request for Proposals (RFPs) to Include Modeling"[8].

The decision process that drives contracting and contracting language should not just define what the technical data requirements are for data/models and delivered computer software. The decision process should reflect how the government and contractor teams make best use of data and models "for operational advantage and increased efficiency" within the context of acquisition and sustainment activities.

The complete value of DE implementation is realized with collaborative knowledge exchange among practitioners of varying activities, and results in improved agility in design, shorter lead times, increased confidence in the end product, and improved product lifecycle sustainability. A related SERC project on DE benefits and measures clearly articulates this value.[9] DE does not necessarily result in cost savings but will improve program timelines and quality if implemented and measured as an integrated process across all engineering. management, and related acquisition disciplines.[10]

The research results from this task reflect the concept of modernized digital acquisition, sustainment, and engineering processes, the value drivers for appropriate contracting of computational/digital elements, and some of the central questions and decision frameworks that should guide program office use of DE to support acquisition and sustainment through efficient and transparent government/contractor interfaces. To take advantage of the current statutory language that supports acquisition, there is a need to develop modernized statement of work and contract language that is useful for practitioners applying digital engineering to new efforts, regardless of the pathway chosen. Additionally, process models of the actual request for proposal and technical evaluation processes need to be developed to reflect the use of modernized practices, with changes to the contracting processes to manage the exchange of data and models, instead of documents, at both the government-to-government levels and government-to-contractor interfaces.

The body of this report begins with a summary of the recommendations in this report. Section 3 sets the stage with a summary of a pilot effort conducted by SERC/AIRC and the Naval Air Systems Command (NAVAIR) to demonstrate a fully model-based acquisition process. Section 4 summarizes the pain points that are delaying full program office adoption of DE, and the lifecycle model for acquisition process integration developed in the SE Modernization (SEMod) project. Section 5 discusses the importance of and requirements for the DEAE. Section 6 provides some historical examples of data and model-centric acquisition as a means to further describe the desired acquisition process integration. Section 7 discusses the policy basis for DE-enabled acquisition and necessary issuance improvements. Section 8 discusses the demand signal for DE-

[7] NASA-HDBK-1004, NASA Digital Engineering Acquisition Framework Handbook, April 2020. https://standards.nasa.gov/sites/default/files/standards/NASA/Baseline/0/2020_04_01_nasa_hdbk_1004_approved.pdf.

[8] CMU/SEI-2021-SR-035, Guidance for Tailoring DoD Request for Proposals (RFPs) to Include Modeling, April 2022. DOI: 10.1184/R1/16602341.

[9] McDermott, T., Henderson, K., Salado, A. and Bradley, J. (2022), Digital Engineering Measures: Research and Guidance. INSIGHT, 25: 12-18. https://doi.org/10.1002/inst.12366

[10] Practical Software and Systems Measurement, DE Measurement Framework ver 1.1. https://psmsc.com/DEMeasurement.asp

enabled acquisition. Section 9 defines a decision analysis framework that can be used to inform DEAE selection. Section 10 lists some of the discoveries made by the research team that can inform future work, and closes the report with some next steps that relate to the larger recommendations in section 2.

2. Recommendations

Lifecycle management activities for models, in total, should extend beyond the acquired system to equally cover the authoritative data and models, their development environments, and especially, non-engineering uses. In the system lifecycle, the Government must be prepared (at the appropriate time and defined in the Acquisition Strategy and Acquisition Plan) to manage and further develop data and models as an organic *enterprise resource*, to be reused, recast, or modified if appropriate. These activities need to be developed and approved in the LCSP, SEP, and TEMP, as well as planned into program requirements, SOW, and IMS/IMP. Thus, **digital artifacts are more than just product deliverables; they must be contractually required in a way that ensures they convey complete and common understandings, for a continuum of use, not only between the DoD and the contractors but across other functions and the product lifecycle and beyond**. From this research, additional broad recommendations were developed. As a next step, this team (if funded) would move from broad to specific recommendations, with a specific pilot implementation using one or more ongoing acquisition programs at various lifecycle stages.

1. Services should develop appropriate enterprise strategies for governance and support of the system ASOT and DEAE and define, develop, and train to, appropriate templates for Acquisition Plans. Data and models and other components of product ASOT, as well as the DEAE, should be identified and planned in the agency's Acquisition Plan as defined in FAR Part 7.[11] Since data and models and the associated DEAE are associated with the system, a system basis should be used for planning (expand beyond an individual contract or order). *The research team did not find any examples of Acquisition Plan language for acquisition with DE*.

2. Services should define appropriate product support strategies and LCSP templates for the ASOT and DEAE at the enterprise level. Digital data and models are products and should be represented in the system Product Support Management Plan as defined in DoDI 5000.91 and the system LCSP. The LCSP outline version 3.0 section 4.6.3 "Digital Product Support" provides high level guidance for both digital product data and the DEAE. *The research team did not find any examples of program LCSP language for acquisition with DE*.

3. A mature Digital Engineering and Acquisition Ecosystem framework will allow program offices and associated personnel to use their practice and expertise to determine what activities they need to do in, and with, the DEAE. NASA-HDBK-1004 has a comprehensive description of the components and operation of a DEAE framework, but no equivalent description exists in DoD guidance. The actual DEAE implementation will vary by acquisition pathway and program objectives*. The SE*

[11] https://www.acquisition.gov/far/part-7

Modernization project found a lack of mature DEAE reference implementations were inhibiting government adoption and that the DoD should invest in development of DEAE concepts of operations and reference tool and use patterns.

4. *The research team recommends that, consistent with existing standards as much as practical, a set of Data Exchange Exemplar Reference Implementations be developed to aid in maturing data constructs, data exchange mechanisms, security architectures, and configuration management provisions* to realize the vision noted in the Systems Engineering Modernization report. Data constructs, data exchange mechanisms, security architectures and configuration management processes are tied together, and are referenced/ directed, and encouraged from disconnected organizations, policies, guidance, and other issuances*.* The DEAE is an Enterprise Information System and is thus covered by the DoDI 5000.82 Acquisition of Information Technology[12] and associated Requirements for the Acquisition of Digital Capabilities Guidebook.[13] The DoD Chief Information Officer (CIO) office is a major player in data exchange policies and guidance. This office is tasked to support other areas as well, and may not understand the full nature of the acquisition and sustainment communities. Meanwhile, within the shift to DE-enabled acquisition, much of the transformation is still manual interpretation of disparate data and analyses.

5. *The research team recommends long-term evolution of the SEP and TEMP to digital resources as noted in the SE Modernization Report.* Programs should define acquisition with DE across all requirements of the SEP in any AAF pathway, and not as a separate appendix. As the SEP is generally referenced as the authoritative guidance for DE, the DoD SEP Outline Version 4.1 should be regularly updated to reflect evolving practice and lessons learned for acquisition with DE.[14] At this point the SEP outline defines a separate Digital Engineering Implementation Plan as an Appendix to the program SEP covering the DE architecture and digital tool chain. In the long-term a fully digital SEP is recommended that defines ASOT governance and DEAE implementation by reference to the appropriate digital environments.

6. Very few acquisition and sustainment activities are underway which are deemed to be digital in nature. In order to populate a DEAE and establish an ASOT that is 1) usable by government and contractor teams, 2) across all activities within a program lifecycle, 3) as a matter of common and best practice rather than something new to be attempted, *the research team recommends that an inclusive review of DIDs, CRDLs, from sample program office contracts, as well as issuances be reviewed and suggestions for revisions developed, in order to enable modifications of, and computational use of the artifact, in a continuum across the relevant acquisition activities*.

7. *The research team recommends that policies and guidance on the AAF site, be reviewed and suggestions offered to increase the strength of digital transformation and connectivity*. The AAF represents an evolutionary change in acquisition thinking.

[12] DOD Instruction 5000.82 Acquisition of Information Technology (IT), April 21, 2020.

[13] Office of the Department of Defense Chief Information Officer, Requirements for the Acquisition of Digital Capabilities Guidebook, February 2022.

[14] Systems Engineering Plan (SEP) Outline, Version 4.1

In reviewing the issuances on the Defense Acquisition University's (DAU) AAF website it is evident that there is language in the collection that implies a digital transformation within the technical functional acquisition activities. However, this DE-enabled continuum is not linked from data sender to receiver, through the policy and guidance.

8. *The research team recommends workflow guidance for DE-enabled acquisition and sustainment for program management offices and staff be drafted*, as a means to close this gap in the transformation guidance and continue with the acquisition activities evolution in the AAF. There is a knowledge gap with the lack of the top-down, supporting digitalized-view from the Program Manager (PM). Neither the Guide to Program Management Business Processes[15] nor the Guide to Program Management Knowledge, Skills and Practices[16] in the current DAU Acquisition Guidebooks discuss any aspects of the ongoing DoD digital transformation and its impact on management of acquisition programs.
9. *The research team recommends that benefits of digital transformation be developed for each pathway, and for each decision point within each pathway, targeting the "why" of digital transformation and away from directed change. Furthermore, the research team recommends that programs quantitatively measure their engineering progress using DE tools.* It is typical to claim the need to invoke technical and process advancements, because it is required. In reality, this is not always true. In the time since Digital Engineering Strategy, DoD Data Strategy, and AAF have been released, research has been conducted and published related to measuring value of different areas of digital transformation, and DE. Digital Engineering will make many engineering activities explicitly a continuously measurable that were previous only assessed at program milestone reviews.
10. *The research team recommends that a strategy, and overarching roadmap for digital transformation of the acquisition, and eventually sustainment processes be developed* to aid in decision making process for what and when to digitalize; separately, and similarly for the sustainment system. Digital transformation is a complex task. The acquisition and sustainment processes are also complex. For the engineering community, the release of the Digital Engineering Strategy, containing the "what" that needs to be done led the shift towards digitally-based engineering to support design and development.

3. Lessons Learned in a Digital, Model-based Acquisition Surrogate Pilot

In 2013, the NAVAIR initiated an effort through the DoD Systems Engineering Research Center (SERC) to explore the technical feasibility of a transformation of NAVAIR systems engineering and acquisition practices to use more advanced and holistic approaches to

[15] DAU, A Guide to Program Management Business Processes 2022, https://www.dau.edu/pdfviewer?Guidebooks/DAG/A-Guide-to-DoD-Program-Management-Business-Processes.pdf

[16] DAU, A Guide to Program Management Knowledge, Skills and Practices 2022, https://www.dau.edu/pdfviewer?Guidebooks/DAG/A-Guide-to-Program-Management-Knowledge-Skills-and-Practices.pdf

model-based systems engineering (MBSE). The resulting NAVAIR Systems Engineering Transformation initiative characterized an overarching digital approach for integrating different model types with simulations, surrogates, systems, software, hardware, and components at different levels of abstraction and fidelity across disciplines throughout the lifecycle. The research efforts starting in 2017 developed a "surrogate pilot" concept to assess and refine the execution of the transformation framework through a series of experiments conducted as evolving pilot projects. The emphasis was on a new operational paradigm to mission and systems engineering, analysis and model-based acquisition, which would be led by NAVAIR with collaborative design efforts led by industry and academia. The expected benefits included:

- **Improved acquisition** – Digital deliverables could improve the government's understanding of a project's status and risk along with allowing a project to validate the contractor's deliverables.
- **Improved efficiency and effectiveness** – A common, shared source of truth would reduce time and effort in the performance of existing tasks.
- **Improved communication to reduce risk** – Using data and models and a supporting infrastructure to translate and extract useful information among a variety of models and model types could allow for improved communication among specialists.
- **Improved designs and resulting solutions** – Being able to understand the impact of requirement and/or design decisions early could help improve the overall system design and identify adverse consequences of the design before committing to a design choice.

The research developed an acquisition framework formalizing the use of models including multiple levels of models, multiple types of models, and a conceptual boundary between government and contractor models as shown in Figure 1. This concept reflects on a government-led ''initial system model'' as part of a ''requirement'' for a request for proposal that would be elaborated by contractors during source selection into a ''final system model.'' The government models focus on Mission and Systems of Systems (SoS) capability analyses leading to requirements and Key Performance Parameters (KPPs). At the contractual boundaries, industry leads a process to satisfy the conceptual model addressing the KPPs, with particular focus on Performance, Availability, Affordability, and other design assurance analyses to create an Initial Balanced Design. Both government and contractor teams continuously evaluate the system development over time in the models in a consistent execution environment.

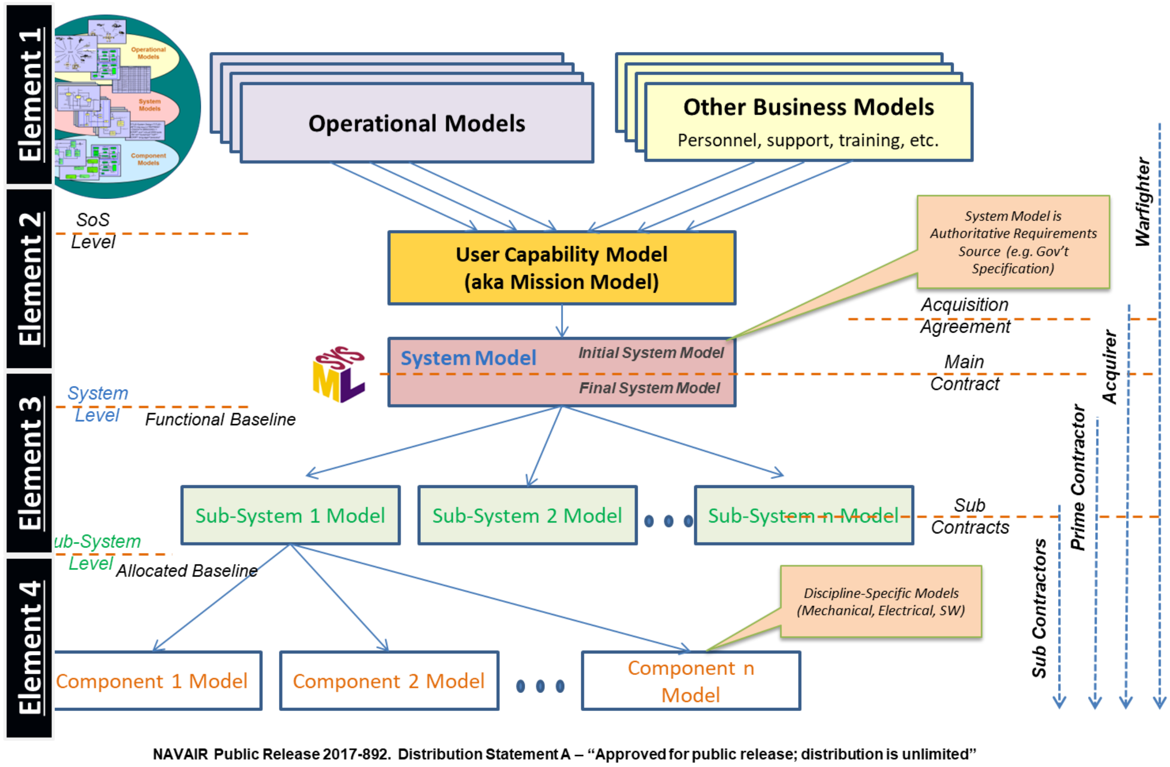

Figure 1. Boundary of models between government and industry.

This approach suggests replacing large-scale document-centric reviews with continual, event-driven reviews which are conducted directly within the model. Using objective and subjective evaluation based on model-centric information, and what is appropriate for the decision to be made, digital signoffs within the model signify there is enough evidence within the digital information to pass a review, based on the exit criteria for the review, or as defined in the digital-centric CDRL. The primary research question was: ''What is captured in data and model-based authoritative source of truth that provides insight into the evolving/maturing design in order to provide effective insight/oversight and make decisions?'' Note that this research question transcends how do we contract for data and models and asks how do we best use them in the acquisition and sustainment decision making processes?

Piloting the Digital Engineering Ecosystem

The surrogate pilot experiment had limited progress until the project deployed a common, shared Digital Engineering Environment (DEE) for all the government elements as shown in Figure 2. The capabilities support modeling, data management, model management, and collaboration through a web-based browser to view the information generated from the model. This is more than a tool infrastructure; the surrogate pilot captured the program workflow as well as standardized model views for different roles and disciplines involved in the program office functions.

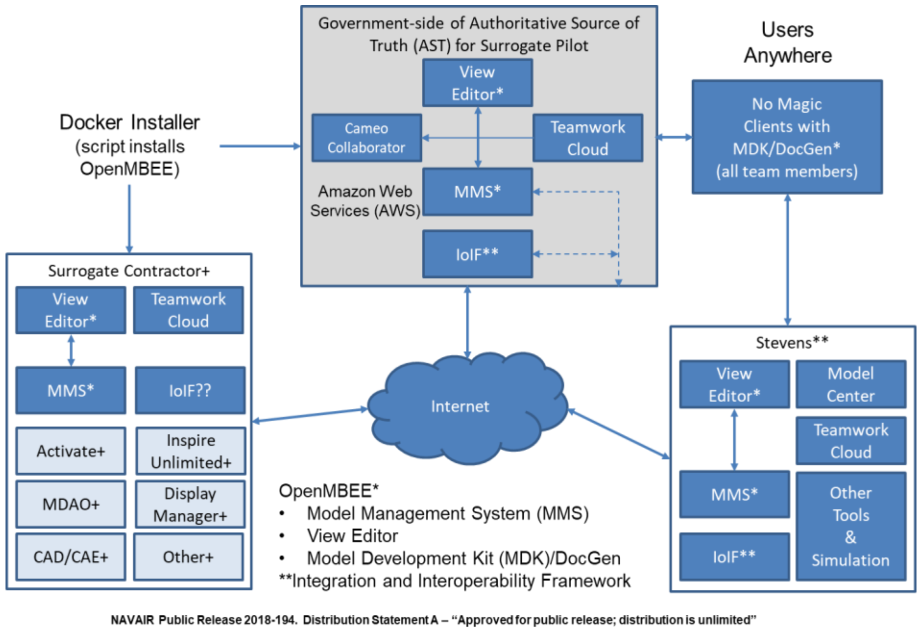

Figure 2. Digital Engineering Environment (DEE) Elements of an Authoritative Source of Truth.

The surrogate pilot activities were conducted as a set of experiments to inform the art of the possible in a surrogate, DE-enabled acquisition program and have been publicized to provide lessons learned to the engineering and acquisition communities.[17] Lessons from the experimental results include:

1. Understanding the "full stack" of government and contractor models needed to fully inform an engineering and manufacturing development program.
2. Formalization of the RFP source selection process as a process model and performing the Technical Evaluation directly in the DEE using Digital Signoffs.
3. Linking these models to government stakeholder analysis tasks such as Reliability and Maintainability (R&M), airworthiness, and life-cycle cost certification as well as piloting digital formal approvals of review artifacts and CDRLs in the models.
4. Example DEE infrastructure tools as well as tool and process integration with data and model management.

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[17] Blackburn, M. R., J. Dzielski, R. Peak, S. Cimtalay, T. Fields, W. Stock, S. Panchal, J. Sisavath, G. Rizzo, Transforming Systems Engineering through Model-Centric Engineering, Final Technical Report SERC-2021-TR-012, WRT1036 (NAVAIR), August 3, 2021.

Blackburn, M. R., M. A. Bone, J. Dzielski, B. Kruse, R. Peak, S. Cimtalay, M. Ballard, A. Baker, A. Carnevale, W. Stock, A. Ramaswamy, M. Szostak, G. Rizzo, W. Rouse, D. Rhodes, M. Austin, M. Coelho, Transforming Systems Engineering through Model-Centric Engineering, Final Technical Report SERC-2020-TR-009, WRT1008 (NAVAIR), June 20, 2020.

Blackburn, M., R., M. A. Bone, J. Dzielski, B. Kruse, R. Peak, S. Edwards, A. Baker, M. Ballard, M. Austin, M. Coelho, D. Rhodes, B. Smith, Transforming Systems Engineering through Model-Centric Engineering, Final Technical Report SERC-2019-TR-103, RT-195 (NAVAIR), May 28, 2019.

5. Understanding of the modeling environment View and Viewpoints used to produce stakeholder relevant views of models that are editable and configuration managed by government or contractor.
6. How the government digital RFP and contractor digital RFP response link system models to discipline-specific design and analysis models.
7. Initial characterization of DE benefits and metrics.

Lessons Learned from this Pilot for DE-enabled Acquisition

The "state change" in this digital model-based transformation is earlier characterization of the underlying information for contracts, engineering, assurance, logistics, operations and sustainment, and capability-based test and evaluation criteria. Earlier characterization of this information results in better understanding of how a maturing design increases the clarity of each development task while the risk and uncertainty in the product trend to zero. DE-enabled acquisition and rigorous SE processes reinforce each other to improve development rigor, increase insight, reduce risk, and significantly increase efficiency.

Although technical data and computer software used in this process may still be contractually deliverable, the traditional static exchange of data and models only at major milestones is counter to the value of DE and should be avoided, or at least lessened with a goal of elimination of that practice.

4. Acquisition and Systems Engineering Modernization

In the Future State of Systems Engineering, the INCOSE Systems Engineering Vision describes systems engineering (SE) practices as "model-centric, leveraging a vast library of reusable elements, enabling rapid response to changes in stakeholder needs and technology, while providing the essential methodologies to manage ever-increasing complexity and risk across the systems life cycle."[18] The DoD has embraced this vision in its SEMod effort within OUSD(R&E), which includes Digital Engineering (and by extension digital transformation), MOSA, Agile, and Mission Engineering.[19]

The SE Modernization effort responds to the need to support the DoD acquisition and sustainment activities. As such, these areas have followed rigorous systems engineering processes. Today, there are a myriad of acquisition process changes centered on the need for more rapid deployment of capabilities, better weapon system portfolio management, and efficiencies that PMs must adjust to. Compounding this, many defense capabilities are not only physical; they are software intensive, highly connected, and have

[18] International Council on Systems Engineering (INCOSE), Systems Engineering Vision 2035, https://www.incose.org/about-systems-engineering/se-vision-2035.

[19] McDermott, T., W. Benjamin, Program Manager's Guide to Digital and Agile Systems Engineering Process Transformation, Final Technical Report SERC-2022-TR-0092, WRT1051, September 2022.

McDermott, T., W. Benjamin, Systems Engineering Modernization Policy, Practice, and Workforce Roadmaps, Final Technical Report SERC-2023-TR-0002, WRT1058, April 2023.

extensive automation and user configuration capabilities. There is a need for standard guidance for program Systems Engineering supporting acquisition and sustainment that incorporates a holistic digital approach inclusive of the entirety of SEMod, the six AAF acquisition pathways and the digital transformation outlined in the DoD Data Strategy.

The SEMod policy analysis found the common modernization driver in all of these focus areas and pathways is data transfer for decision making: seamless and efficient transfer of data and models from underlying performance drivers through models to decisions, as well as ease in the reverse of drilling back down from decisions through data to performance drivers. This does not mean everything must be connected but that the process to move up and down the data transformation space is efficient and produces better, usable quality data. With this mental and process model of improved access and flow, a common integration framework for engineering and acquisition and sustainment can be pursued. Without it, stove-piping of people, processes and tools across lifecycle stages will continue to be practiced. The base intent of SEMod is thus to support **more seamless and efficient digital integration of data and models across all program management, engineering, and acquisition and sustainment functions**. The SEMod project found this intent to be generally lacking in the current policy and guidance.

The effort envisioned the primary goal of integrating SEMod is to **create a more agile and responsive acquisition system that can quickly and effectively meet the needs of the warfighter**. In spite of recent modifications, acquisition guidance and supporting SE guidance still operates with a tone of linear, milestone driven technical and in SEMod, data is transformed through models into views, which support analyses leading to decisions; so far, so good. However, coupled with the linear acquisition guidance, these transformations and resulting documentation artifacts still become disconnected from the underlying data and models as they are captured in independent static document or presentation forms. The current culture of delivery of written, static, technical data is proving difficult to overcome in the DoD and defense industrial base.

This research developed a new visual model of a systems lifecycle – the "supra-system model" – that is continuously iterated and layered from data to models to decision artifacts. The Supra-system Model is shown in Figure 3. This view is an attempt to capture everything associated with DoD engineering and acquisition and sustainment in one visual representation. It must be tailored and redrawn based on differing types of development, delivery, and support processes required for each acquisition. With study, this new visualization becomes insightful:

- it illustrates the DAS as a cyclic activity, rather than a linear one, and the usefulness of the data and models exists longer than the length of just one program lifecycle.
- the integration framework makes the digital transformation necessarily clear using a layered visualization with data storage and transformation at the core, models as the data transformation layer, and systems engineering and acquisition and sustainment process areas as the outer layers.
- the data and models may come from any experience of a system, including pre-Material Development Decision (MDD) through post Operational Test and deployment, and support.

The model offers an end state for integrated SEMod: **new SE lifecycle processes must evolve that address shared and authoritatively managed and used sets of digital data and models associated with the full lifecycle of the system itself, not just a single acquisition program lifecycle.**

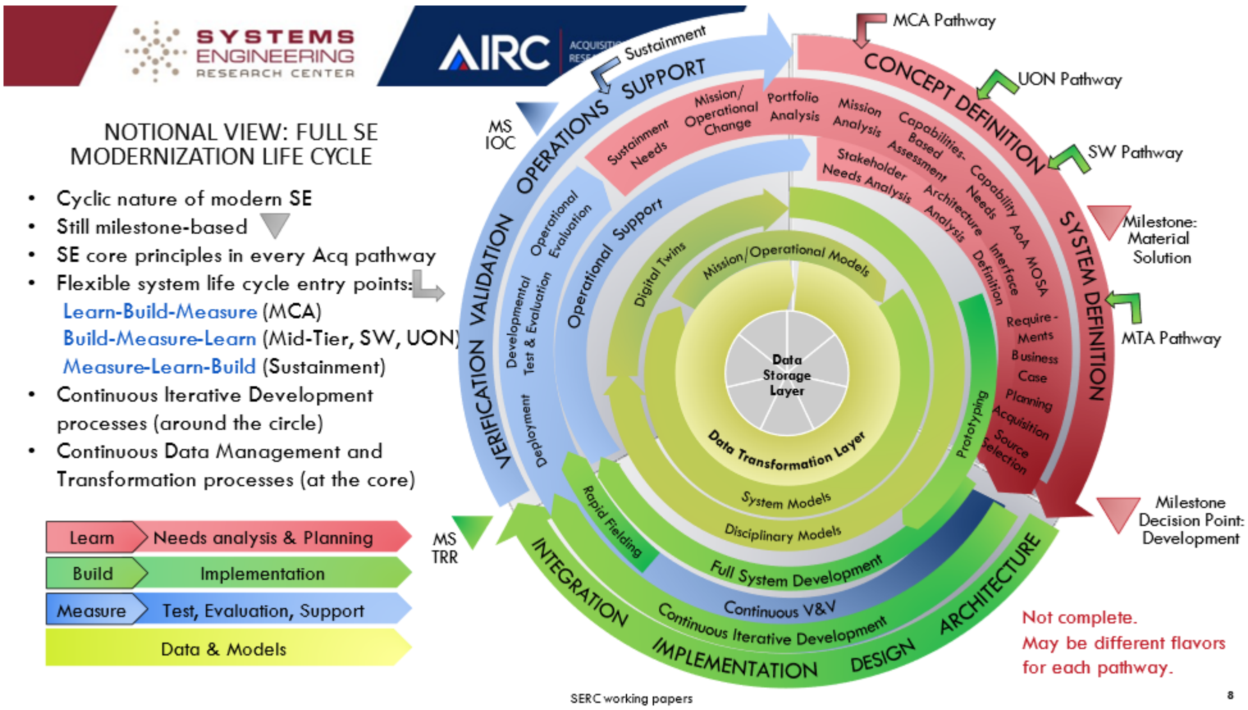

Figure 3. The Supra-system Model: all acquisition activities continually iterating around data and models.

Throughout the SEMod project, the team conducted outreach to government functional area leads, system program offices, science and technology organizations, professional societies, and other commercial entities who could discuss their SEMod experiences. These discussions, and this Supra-systems model visualization, led to a comprehensive set of pain points that were developed to inform future SEMod roadmaps. Some of those pain points represent acquisition and sustainment stakeholder needs as well:

- lack of fully integrated DEAE reference implementations (poorly integrated tools flows and effective practices for sharing data and models)
    - need resources: high labor and tool costs can make this unaffordable
    - need integration of engineering and program management related data
    - need to build a culture of collaborating/sharing
    - need effective configuration management processes for data and models
    - need to develop intellectual property management processes
    - need to develop and apply contractual incentives to share data and models
    - need tool suites that provide means to view/extract data at different levels
    - need to standardize on data and model storage and access approaches

- poor understanding of the value of DE across all acquisition and non-engineering functions
  - need engineering and acquisition DE-enabled processes and methods
  - need PM guidance for using models as a risk mitigation strategy
  - need dedicated resources to for implementation of new methods and tools
  - need schedule and program planning that includes training
  - need revised/more complete cost estimation tools for data/model collection
  - need examples of realized program office efficiencies
- lack of ways and means to drive adoption in program offices (lack of acquisition process integration and policies that fully incentivize digital transformation)
  - need terminology/ontology across all acquisition and engineering functions
  - need examples of legacy system adoption of DE and MBSE
  - need contracting approaches/templates for collaborating around models
  - need more examples of acquisition artifacts resulting from data and models
  - need progress visualization approaches to model based acquisition
  - need affordability improvement using enterprise-wide infrastructure funding
  - need portfolio/program approaches/examples of data/model sharing
- lack of modernized engineering and technical management processes (data/model governance and agile and continuous review processes)
  - need to develop and mature libraries of data and models
  - need examples of data/model portfolios in program offices
  - need processes for acceptance and validation of authoritative data/models
  - need better decision processes for establishing program data/model needs
  - need digital information exchange standards for tech/program reviews
  - need visualization standards for tech/program reviews

Implications of SE Modernization for DE-enabled Acquisition

Modernized engineering, acquisition, and sustainment practices must be articulated in a way to maintain information connectivity across the system life cycle, to benefit future decision making, and allow reuse of the artifacts themselves. Digital decision artifacts, by their nature, can easily remain digitally connected to the underlying data and models that were used in their creation. This advantage for the PM and staff provides enormous insight and historical corroboration for the decisions that were made to advance the program. The information contained in the relationship between the decision and the underlying data of that decision can help determine applicability of that decision in other programs as it provides the context for the decision.

Decisions can be traced back to, and futuristically impact mission outcomes, system design, and deployment/sustainment operations. Design choices can be analyzed, validated, or modified to take advantage of new technology, different design options, or changes in threats, for example. This connectivity spans all processes associated with weapon systems and capabilities across the lifecycle. Both government and contractor cost and schedule options can be analyzed, and positions on needed resources established; all backed up with data.

Using the available digital linkage, it may be possible to establish connection with logistics and transportation options far enough in the future to predict resource savings or needs for downstream users. Functionality in design, like agility and modularity can be used as design options to achieve maximum, expected performance of the system for the user, assuming the processes, guidance and policies for the acquisition and sustainment community are created or modified to take strategic and tactical advantage of the digital connectedness possible.

5. The Digital Engineering and Acquisition Ecosystem (DEAE)

To realize the objective of an integrated, DE-enabled acquisition, careful thought must be given to the underlying environment with which the data that informs these models is managed, manipulated, and used. It cannot be understated: **Following a systems engineering process, a system architecture and design should be used to construct and contract for the target DEAE environment**. After all, the DEAE is a system in and of itself. This effort must be available and ready at the initiation of any program or project. Not surprisingly, and just as with any system development, it is the integration of the decision making that will result in a functional and usable DEAE. There is a series of decisions, that are described later in this report, to be made based on the acquisition strategy, program execution strategy, and technical requirements for the system under consideration. Figure 4 below illustrates the integrated objective of an ideal DEAE. The Exemplar Reference Implementation (ERI) highlights attributes of a DEAE that is tool agnostic and enables contributing stakeholders to be tightly integrated. Conceptually there will exist a configuration managed set of system data that is authoritative for technical development, programmatic execution and eventually lifecycle sustainment. This data does not need to be physically stored in a single location to be considered the authoritative source of truth and is virtually constructed to an intended data model/architecture. The connected networks which enable this DEAE will not be static as organizations perform maintenance on their hosting environments. Care must be taken to ensure the architected DEAE remains resilient to the evolving system of systems.

The major components of the DEAE ERI are a data repository or set of connected repositories for technical and programmatic data and has the necessary cybersecurity provisions to comply with the control requirements for the system under development which will use the DEAE. Ideally, but not necessarily cloud native, this structure will enable government agencies and the contractor base to each access the system data in a secure and controlled manner. As noted in the Section 3 NAVAIR pilot program, it was vital that each impacted stakeholder and contributor have access to a single repository. Federated ASOT and tool access via some kind of cloud native environment enables such connectivity. A common data model must be constructed that ensures all necessary stakeholders can access the information necessary to function in their role. Data copy/transfers should be eliminated wherever possible, replaced by data exchanges as enabled through this infrastructure, eliminating the risks with duplicated and stale data.

Each function in the DE-enabled acquisition processes should be conducted through the tooling systems of the DEAE that have been selected by the organization responsible for managing and using the specific data. Open tooling Application Program Interfaces (APIs), carefully selected, allow for translation of the authoritative system data via data exchange mechanisms. Systems engineers, hardware developers, software developers, testers, production designers, sustainers, and program office personnel can operate in their native tool suites.

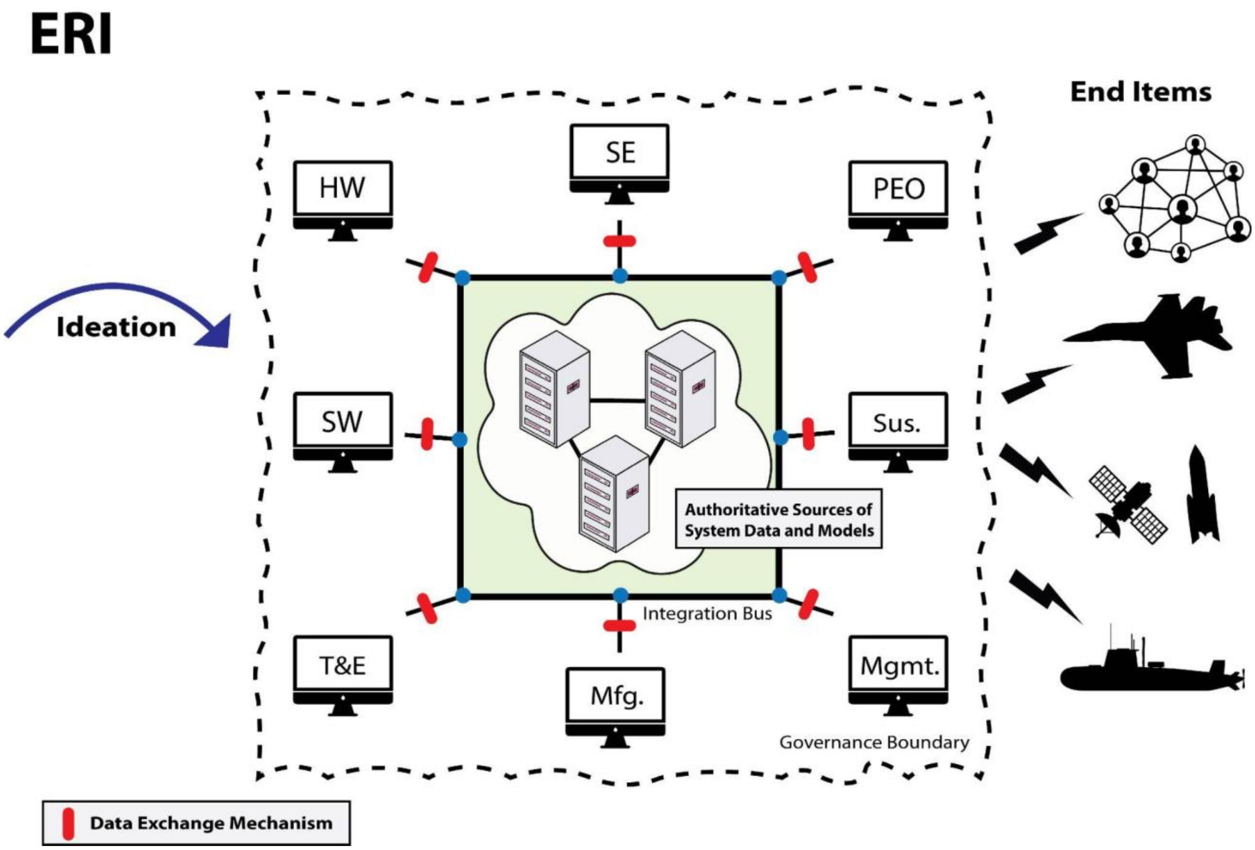

Figure 4. Operational view of the DEAE.

Figure 5 below exemplifies the nature of the data exchanges deemed necessary to develop, produce, and maintain a DEAE. Advances have been made to automate these information exchanges; however, there is still customization work to be done to mature this into a resilient, stable construct for any DE-enabled acquisition and/or sustainment effort. When functioning, there will be a seamless connection between the system design to the detailed design, to test and evaluation, to production, to sustainment, and potentially to other programs' use. These connected data exchanges enable digital twin creation and use of resultant physical systems for improved production and sustainment.

Contracting for the Digital Engineering Acquisition Environment

There currently is no evidence that all program offices are familiar enough with current policies and state of the art DE or SEMod practices to navigate the decision space for contracting for DEAEs. Programs of record often find it easiest to stay with their legacy contract vehicle and development environments, even if doing so is not the most resource-effective decision. Contracting for the DEAE will be shaped by the example decision analysis framework described below. Due to challenges with tool interoperability, et al, each program will have to traverse a decision framework to determine what environment provides best value, supports as much of the collaboration desired, minimizes IT and tooling costs, complies with security requirements, and provides connectivity to required stakeholders, contributors and users. Once basic requirements are established for the DEAE, a program office should exercise caution when determining what data deliverables are required as there may be additional costs and administrative control concerns caused by over-specifying data requirements. In addition, each DEAE architecture, design and procurement decision should ensure compliance to DoDI 5000.82, Acquisition of Information Technology (IT) as the DEAE is part of a greater IT management strategy. Additionally available, NASA has established a handbook, NASA-HDBK-1004, NASA Digital Engineering Acquisition Framework Handbook to aid its departments in contracting and managing a DEAE. This handbook is useful resource for DoD agencies to consider as they navigate through the development and maintenance of DEAEs.

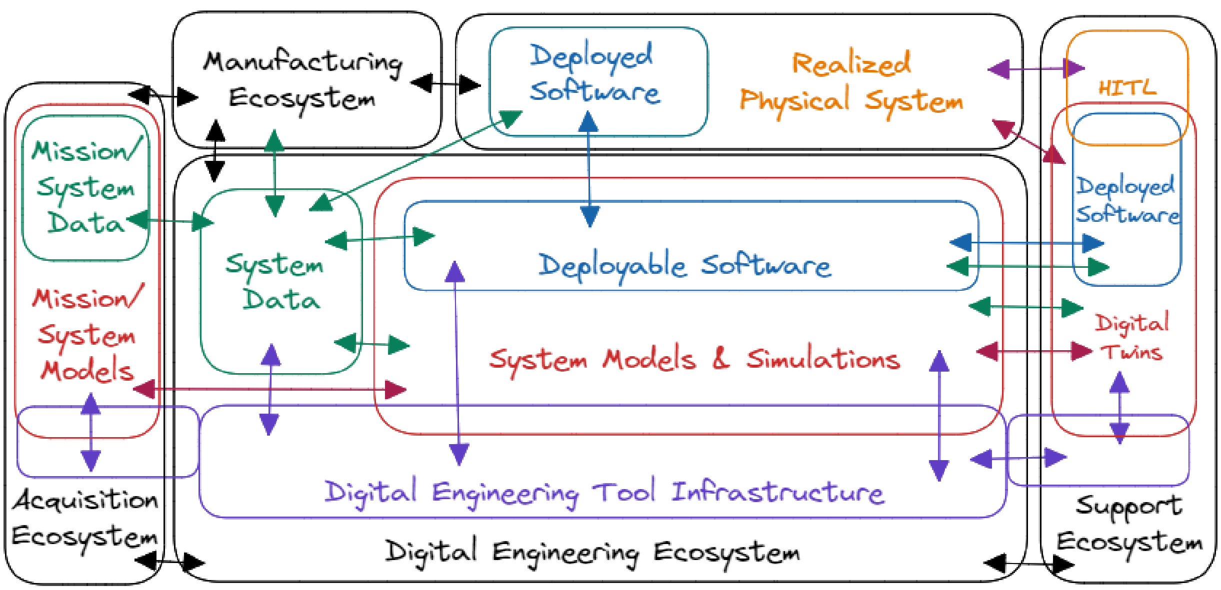

Figure 5. Life cycle data exchanges in the DEAE.

The Decision Analysis Framework

The architecting of this environment is vital early in the decision-making process for issuing a Material Development Decision. DEAE decision making must be matured to architect and maintain a DEAE that supports a system through its entire lifecycle. This decision analysis framework is necessitated by a series of interdependencies that require further maturation for a program office to proceed confidently into an acquisition and/or sustainment. The assessment leads the enquirer through decisions on data and intellectual property it truly needs to own and control versus a perspective that the government must own and control everything. The interactions of tools and tool configurations in the future do not lend themselves to delivery of a technical data package in a large document-based construct. To truly take advantage of the digital environment, and digitally transformed acquisition and sustainment, appropriate risks for the DEAE must be evaluated and managed, and best solutions derived.

Since there is not a “one size fits all” solution to contracting for these environments, the contracting decision will be shaped by acquisition pathway from the AAF, contract geometry selections, maturity of the system under development, the life stage and life cycle of the acquisition and sustainment, the users shown in the ERI, among other factors. This research has established a preliminary set of interview questions and has begun exploring the interrelationships between these questions and who in an acquisition and sustainment process is best suited to answer these questions. The questions explore existing reference architectures (such as the one depicted in Figure 4) and tooling suites, how program and technical reviews will be conducted, plan for architecture management, design decision authority and control, sustainment strategy for the system under development, connectivity requirements for supporting businesses and agencies, and contracting construct. All these areas are explored with the intent of providing the best decision of value for procuring service and the warfighters. Figure 6 focuses on the decisions of the procuring component, the Program Office, and the LSE/Chief Engineer for an acquisition.

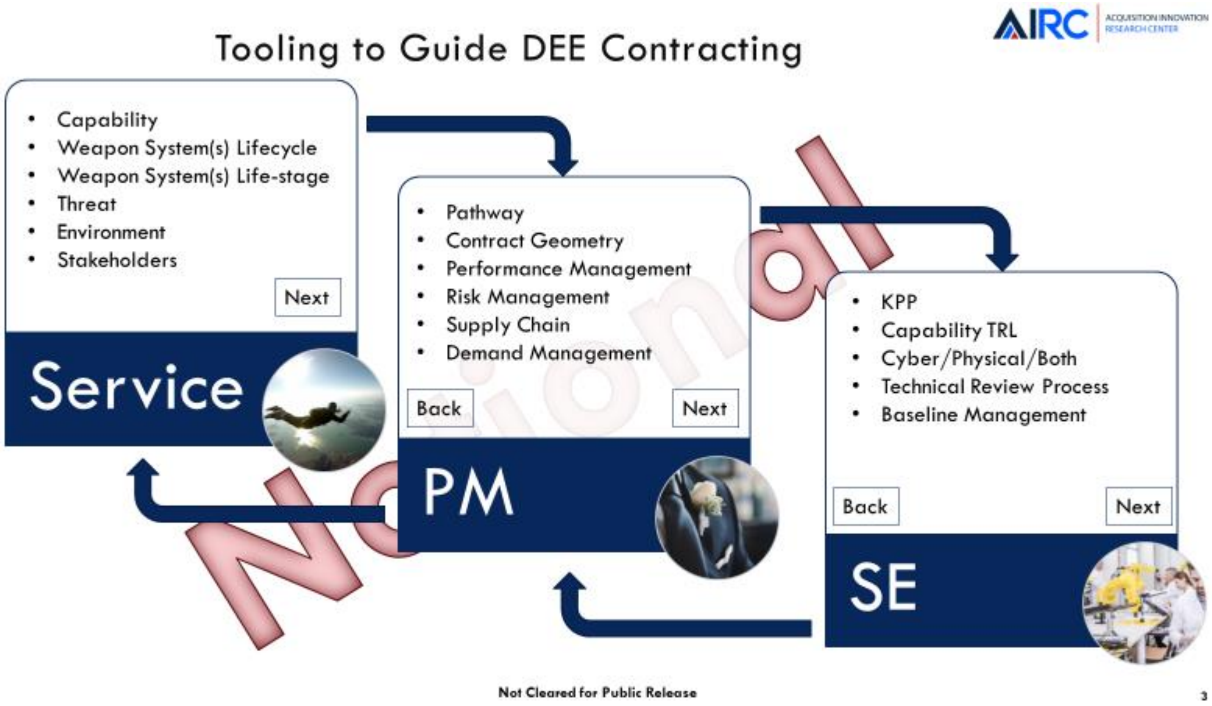

Figure 6. Decision framework for acquisition with DE.

6. Baseline Examples of DE-enabled Acquisition and Sustainment Processes

SE Modernization calls for the seamless and efficient transfer of data and models from underlying performance drivers through models to decisions and back down to the originating data. This is critical to DE-enabled acquisition and sustainment activities. Correspondingly, systems engineering and related processes can be visualized as a set of data transformations from sources of truth that produce artifacts for human consumption – across all stages of a system life-cycle. One way to consider this effort is to draw on sections of the AAF in which these maxims are already established. Two example process areas are reliability and maintainability (R&M) and intelligence mission data (IMD). R&M data and models are typically derived from contractor development and test activities and managed by the government, while IMD data and models are derived from government data and models and provided to contractors to drive their development and test activities. Each of these is instructive as a combined government/contractor data governance activity that has generally already implemented DE concepts.

Within USC, Title 10 section 2443 links design factors to sustainment factors, including R&M as performance attributes within the requirement process. The AAF follows this statute, with a course of action that flows from 5000.01, through 5000.02, and into 5000.88, the Engineering of Defense Systems. The Engineering of Defense Systems Guide provides a good starting point to explore what a set of digital transformations can provide to a subset systems lifecycle and associated acquisition and sustainment activities: R&M to program support management. It follows the intent of the statute and adds the supporting actions for digital transformation: "For all defense acquisition programs, the Lead Systems Engineer (LSE), working for the PM, will integrate R&M engineering as an integral part of the overall engineering process and the digital representation of the system being developed." It further goes on to articulate the R&M plan inclusion of "engineering activities, products, and digital artifacts." For the Product Support Management part of the AAF, of the weapon systems development and fielding, the 5000.91 likewise includes the interchange of responsibilities between engineering and acquisition and sustainment offices, and includes activities which directs exchanges between the systems engineering, and product support engineering communities, using digital methods and digital artifacts.

In both the R&M and Project Support Management (PSM) communities, further guidance comes through other collections of sage advice such as the R&M body of knowledge, and the PSM guidebook. These are not directly referenced through the AAF, but they are developed and maintained by the practitioner communities, and demonstrate an in-depth understanding of the value of digital transformation, and data exchange. Changes to DIDs, and CDRL language are in work, or have already been completed. This demonstration of needed data exchange between engineering and acquisition and sustainment communities is key to the successful digital transition of the OUSD(A&S) activities.

Similarly, intelligence products tend to be data-driven and equally critical across development and sustainment activities. DoDI 5000.86 Acquisition Intelligence states that the SEP must address modeling and simulations that "provide characterization of the threat in comparison with the capability requirements." Programs must also define a Life-cycle Mission Data Plan (LMDP) that must articulate how the program and other organizations intend to address specific program needs for intelligence mission data required to operate mission systems in accordance with DoDD 5250.01 Management of Intelligence Mission Data (IMD) in DoD Acquisition.

The Intelligence Support to the Adaptive Acquisition Framework (ISTAAF) Guidebook, September 2021 states "Baking-in digital interoperability for growing the DoD digital ecosystem is paramount to remain ahead of our adversaries. To this end, any machine-to-machine interfacing is beneficial. When digital interoperability is considered from the start, the growing list of digital Intel threat products can feed and improve a program's development decision choices (i.e., supporting Digital Engineering), analysis of alternatives, testing environments, Critical Intelligence Parameter (CIP) breach reporting, and eventually artificial intelligence capabilities that can reduce dependencies on manpower-intensive processing." It notes these as being applicable to all AAF pathways.

Development, maintenance, and verification/validation of IMD is a continually occurring process that affects developmental planning and requirements activities, developmental modeling and simulation activities, developmental and operational test activities, and equally operational sustainment, IMD development, related V&V, and government and contractor provided toolsets. Key decision factors for IMD include:

- scope of the IMD in terms of number of threats and related data, to support adequate estimation of IMD development and test requirements
- governance of the sets of data maintainable as IMD mission data files on the weapon system, including both government and contractor developed
- associated simulated and hardware in the loop development and test environments, as developed to address the full life cycle scope of the IMD
- government access to simulated and Hardware-in-the-Loop (HITL) development and test environments as well as actual weapon systems for V&V

Intelligence products have always been a partner to acquisition with DE, as the related data and models are necessary to support regular and urgent updates to programmed intelligence support data in the weapon system. Lessons learned from IMD support that can inform DE-enabled acquisition include:

- IMD development and test requirements must be defined for the full weapon system life cycle. IMD products are essentially data and models and can provide good lessons learned for larger acquisition and governance of data and models. IMD products are also often maintained by a combination of organic government and contractor provided support.
- Needs for simulation and HITL utilization time must be fully estimated, and documented in the program SOW, whether in contractor or government facilities. Studies of recent program IMD development and sustainment approaches can provide a good basis for broader DE governance strategies.
- As with the DEAE, IMD development and test tools needed to have defined requirements and be developed, matured, and supported across the full weapon system life cycle.
- When government and contractor share responsibility for facilities, government ability for continuous V&V must be planned and may need unique tool configurations and capabilities, similar to evolving DE ecosystems. Evaluation of recent IMD support infrastructure trades could be a useful set of lessons learned for a DEAE.

7. The Policy Basis for DE Artifact Contracting

The DoD (regardless of program Acquisition Category (ACAT) or Major Defense Acquisition Program (MDAP) level) is required to conduct a comprehensive engineering program for defense systems. This is considered an engineering best practice, and is articulated in the SEP. It is required by policy through 5000.88 for all MDAPS, and ACAT II and III programs, unless waived by the SEP approval authority, which is either USD(R&E) or delegate. The SEP, used by the PM to manage the SE activities, is a living technical planning document or blueprint for the conduct, management, and control of the technical aspects of the government's program from concept to disposal and includes elements such as requirements traceability, linkage to system architecture, configuration management, RIO and technical trades and evaluation criteria.

The SEP content is articulated in the SEP Template, v4.0.[20] While a template is not a formally recognized DoD issuance, it is an outline instruction for included content as specified in the 5000.88. Rearrangement, and tailoring of content (which must be approved by the SEP approval authority) is possible. It is imperative that the SEP be complete, as it, and the contract are the basis for the Systems Engineering Management Plan (SEMP). The SEMP is the item that the contractor team is tracked to. There may be very little look-back, or update to the SEP in practice. A possible way to repair this lack of adherence to either plan, is that the SEP become an integrated workflow model. This

[20] Systems Engineering Plan (SEP) Outline, Version 4.1

way, the DEIP can support the template for the workflow and allow the integration of the process, and the DEAE – implementing the digital continuum for acquisition and sustainment.

One of the required elements in the SEP (unless waived) is the DEIP. The description in the 5000.88 could be viewed broad enough to include the references to digital artifacts (if supported by rearticulated DIDs and CDRLs) and the configuration management/curation of such items. The 5000.88 supports reuse possibilities of the authoritative sources of truth, and other relevant data by OSD, Joint Staff, and interdependent programs. Unfortunately, it stops short of enforcing the reuse; and it does not mention anything about sharing of the data with the contracted activities. This implies that the policy basis for the digital continuum of activities, contained within the engineering and management activities documented in the SEP is not enough. In some cases, such as R&M and PSM guidance, the linkage between digital artifacts and activities is strong; in others, it is missing.

It is easy to see how a SEP-articulated digital continuum can support the program engineering and technical activities, and can be used as the authority and support to management activities. For example, an IMP and IMS are not normally considered part of engineering, but draw on and influence engineering activities. The IMP and IMS are by their nature, digital in origin. If properly formatted and documented in relevant DIDs, they could become part of the ASOT within the DEAE, and provide a single source for program management and scheduling across all management, technical, and business activities. Further, the SEP also requires a digital CM approach, including automated tools, furthering the digital continuum. After all, if you have to digitally configuration manage and curate "the schedule, cost, function, physical and performance characteristics of the system" as well as any changes, it both precedes and follows that activities that contribute to, and draw from, the set of curated artifacts are themselves, digital in nature, or at a minimum, produce/consume digital artifacts.

8. Establishing the Demand Signal

Within the DoD acquisition and sustainment activities, SE establishes the technical framework for delivering materiel capabilities to the warfighter. If implemented, it allows the effective development and delivery of capability through the implementation of a balanced approach with respect to cost, schedule, performance and risk and opportunity, using integrated, disciplined and consistent SE activities and processes regardless of when a program enters the acquisition life cycle. Coupled with the INCOSE SE vision, the adoption of digital, modernized SE practices can provide many benefits to the acquisition and sustainment practices if it is adopted.

The DAS is evolving. In 2020, the 5000.01 was signed into effect, directing the document-centric, single DAS evolution, and separated its main acquisition efforts into 6 separate acquisition pathways: Urgent Capability, Middle Tier, Major Capabilities, Software, Defense Business Systems, and Services. These new pathways are directly supported by DoD issuances and guidebooks, and indirectly supported through issuances and guidebooks for supporting practices, such as Systems Engineering. Throughout all of this change, the "mainstay" of systems engineering in the DoD, and associated DoD acquisition guidance, has continued to center on physical realization of large-scale monolithic systems and other critical capabilities intended to persist for many years (now known as Major Capability Acquisition). A new model of a systems lifecycle, based on digital and modernized acquisition activities that are continuously iterated and digitally layered from data to models to decision artifacts, and the reverse must be adopted by the acquisition and sustainment practitioners.

The engineering practitioners cannot push for the acquisition and sustainment use of their digital, modernized practices and expect the same level of effective employment in acquisition and sustainment, that they are realizing within engineering. OUSD(A&S) must be the organization to develop the trend of regular digital, modernized system engineering use within its own acquisition and sustainment activities. The practitioners of acquisition and sustainment must develop a demand signal for modernized engineering practices to speed the consistent and thorough adoption within their own community.

This will have multiple benefits for the acquisition and sustainment community. Demand signals are from the user point of view. Who knows acquisition and sustainment activities, better than that community? Rather than giving acquisition and sustainment practitioners modernized digital, SE practices to use, it is better if those communities provide the background and rationale for what they need to do with the results of digital, modernized systems engineering, and when (priority). Engineering can then adapt the digital, modernized SE practices into the language and culture appropriate for the acquisition and sustainment communities, and have an immediate, and as-requested impact.

By driving the user point of view, acquisition and sustainment communities will be able to prioritize their need for digital, modernized SE practices. The current active OUSD(A&S) and component programs span the spectrum of DoD activities, as well as the entire program lifecycle. They encompass all users of military hardware and software. It is a huge problem space for digital, modernized SE to aim into. The SEMod transformation effort cannot cover the entire problem space all at once, and therefore risks working on something irrelevant to the users, or being spread so thin that no SEMod thrust is active enough to be useful to them.

As discussed by Geoffrey Moore, in Crossing the Chasm, directing an internal shift in the way things have been done is difficult. Attitude toward technology or new process adoption becomes significant any time we are introduced to products that require us to change our current mode of behavior or to modify other products and services we rely on. The AAF has been the first such shift for OUSD(A&S) in over 25 years. The AAF however, does not directly call for technology insertion or adoption related to digital data, digital process execution, or other advances like machine learning. Re-working the acquisition processes to be more focused on product type, without adopting modern computational capabilities is a partial advancement at best.

The easiest way to direct the internal shift is to allow/request that the same tasks be accomplished with different tools. In this case, the tasks to be accomplished lie within the AAF group of DoD issuances and guidebooks, and the tool for adoption is computational capabilities. However, within the AAF group of issuances and guidebooks, not all of the activities and needs are articulated nor are they all connected. One of the major benefits of using computational capabilities, and a key tenet of digital engineering is the continuum of use of the data pertinent to the entire system lifecycle decision making. In order to fully realize this, supported by adoption of digital methods, the acquisition and sustainment activities must themselves be internally connected. Data transitioning from one set of activities to another is irrelevant if the receiver doesn't know what to do with the data, or doesn't even know it is to be expected. The demand signal must be supported by internally consistent, linked transaction of expected data.

The acquisition and sustainment demand signal will document the awareness that change is necessary to advance the practice of acquisition and sustainment; will provide the decision to adopt the SEMod practices by the acquisition and sustainment practitioners, and perhaps most importantly for the practitioners, will include the prioritization of uses. Even that is a very large set. It may be easier if the contributors to the demand signal centered on a set of benefits they are trying to achieve. One such set is suggested in "Digital and Model-Based Engineering: Expectations, Prerequisites, and Challenges of Infusion" paper:

- Informed decision making through increased transparency and greater insight,
- Enhanced communication,
- Increased understanding for greater flexibility/adaptability in design,
- Increased confidence that the capability will perform as expected,
- Increased efficiency

9. Discoveries in the Research Process

There are relatively few available examples of direct contracting for DE-enabled acquisition and sustainment or for specific DEAEs. Much of the existing contracting language is held as proprietary/competition sensitive and the research team did not have access to it. That being stated, some additional feedback was received from DE practitioners and the research team:

- Often the DE methods and supporting environments are contracted in a very generic form thus leaving compliance up to the relationship with the contracting program and the contractor fulfilling the acquisition. Additionally, contracting for specific tools is cautioned against. This practice could contain significant cost, be fragile to maintain, and minimize reuse. Configuration differences of tooling and network environments may pose risk to digital design objective if overly prescriptive.
- Contracting offices should avoid contracting for **digitized** documents thinking they have obtained a DE solution. This practice falls significantly short of the objective of developing and maintaining an integrated data definition of **digitalized** data.
- As stated previously in this report, contracting offices should be very careful in over-specifying the data and IP the US Government must own. The decision

framework described in Section 5 should aid acquisition and sustainment offices in making a judicious decision on data rights.

In reviewing the AAF:

- For the majority of the overall AAF, continuity and communication intra-AAF connectivity is missing. Digital transformation is a necessary, but not sufficient element for a connected AAF. The processes themselves must be related, and the origin and destination of data transfer must be articulated.

- The frame of reference for the AAF is the MCA. This is an understandable choice, given the history of acquisition and sustainment practice and purpose. However, very few of the AAF functional policies and guides provide DE language specific to the pathways beyond MCA. The MCA does include language for suggesting the principles of MCA to the other pathways; but it is largely left to the reader to fill in the details.

- Missing from the AAF collection of policies and guides, is a general summation of the PM responsibilities and actions. Prior to its retirement in 2022, the Defense Acquisition Guidebook (DAG), primarily chapter 1 was "intended to provide PMs information needed to thoughtfully organize, plan and execute a DoD acquisition program…." There are two guides release by DSMC, through DAU, their relationship to the AAF from acquisition practitioner point of view is unknown.

- Assuming that the 5000.85 contains enough information for a PM to confidently execute his/her duties within any pathway or pathways, OUSD(R&E) responsibilities are missing; so, any relationship between engineering and program management is likely missing. There is no way to include the requirement for DEAE, digital transformation, et al as an OUSD(R&E) input.

- The pathway policies focus on the functioning of each pathway requirements as expected. There is some guidance at the DAU sites that supports the 5000.02 direction that in some cases, multiple pathways can be used, and supportive guidance on tailoring-in helpful regulatory information beyond what is necessary for each pathway. However, there is little consideration within some of the pathways for engineering plans and processes to mature technology, use SEMod practices and produce technical baselines, and non-regulatory supporting items.

- A companion to the 5000.88 is the Engineering of Defense Systems Guidebook, released in Feb 2022. It states that "digital engineering is a necessary practice to support acquisition in an environment of increasing global challenges and dynamic threat environment". Unfortunately, digital engineering is still not a consistent policy imperative across the collection of issuances within the AAF.

10. Closing and Suggested Next Steps

Acquisition with DE research (WRT-1057.18g) intended to articulate a contracting process flow, along an AAF pathway and to begin establishing the realization of ecosystems for use by acquisition and sustainment. Research obstacles along the intended path led to shifts in both the methodology and the expected outcomes of this WRT, creating a series of discerning discoveries for the acquisition and sustainment communities, along with the initial practical knowledge of what it takes to realize a DEAE. Even though the research team was unable to examine DE-enabled acquisition and sustainment in practice, enough positive movement of digital transformation was discovered in order to provide a basis for future efforts.

In order to continue along the digital transform of the current acquisition and sustainment practices, some suggestions are captured below:

1. The DE strategy reimagines technical data and associated computing systems as living digital threads and digital twins that live alongside the realized and deployed physical systems across the full life of the virtual system. Suggest and/or mature processes to collaborate across disciplines and organizations fully within digital model-based environments, adopting SAFe workflow patterns as appropriate, to achieve a digital continuum of model and data use within acquisition and sustainment.
2. Examine the configuration management processes, and articulate changes necessary to move from just managing program artifacts, to curating digital data and models. Include establishing high confidence data sources, and how to have it used throughout the enterprise
3. Establish an exemplar DEAE, drawn from reference architectures, to mature the DEAE concept, and provide a space for experimentation in use of the DEAE to support acquisition and sustainment. This DEAE exemplar implementation can also demonstrate the seamless and efficient digital flows across engineering, program management, and acquisition processes, including standard use cases and method/tool patterns will emerge.
4. Further research is necessary to mature the DEAE decision tool framework and construct exemplar contractual language.
5. The 5000.88 is used as the source of required information for the SEP content; likewise the 5000.89 for T&E. The transference of needed elements between the 5000.88, 5000.89, the acquisition strategy, and the SEP and TEMP templates should be carefully reviewed, and options offered to strengthen consistency, and digitalization.
6. Develop a digital process to develop a digital SEP, and /or a digital LCSP, to demonstrate the ease of developing and using these digital artifacts.
7. Building from the work done by SERC/AIRC for NAVAIR and SPACECOM, draft an exemplar of all necessary items for successful MDD for MCA; and extend to other pathways.

8. A tremendous amount of useful information is put into acquisition planning and the actual acquisition strategy. Evaluate the acquisition planning guidance, and the acquisition strategy template, as well as those strategy elements that are added to the acquisition strategy along a program timeline, and make recommendations for how to strengthen the digitalization of the artifacts, including the acquisition strategy template itself.

9. Beginning with activities that are digital in nature, and with digital artifacts already suggested in the AAF, such as within the Engineering of Defense Systems Policy (5000.88), develop DID and CDRL modifications, and recommended guidance, referencing the R&M/PSM, and Intel areas.

10. As long as digital transformation is considered in tandem with digital engineering, it will suffer from lack of engagement whenever digital engineering can be tailored out, or is not required; similarly, with SEMod. In order to digitally modernize acquisition and sustainment, the research team suggests different facets of attack to digital transformation:

    a. Consider digital transformation as a separate concept for acquisition and sustainment practices

    b. Tackle the digital transformation by starting with the statutory and regulatory items necessary for successful acquisition in the DAU AAFDID. Since these are mandated, it may provide an incentive to pay closer attention to the digital methodologies and data flows necessary to create them.

    c. Engage the pathway communities to clearly articulate their pathway processes as much as practical in the digital space envisioned in this report.

    d. Move one level up from the particulars of the AAF, and project a top-down, digital transformation encompassing the JCIDS, PPBE and DAS; bringing the DoD Data Strategy to life across major elements of the spectrum of activities in the DoD.

    e. Begin with intelligence, reliability, and maintainability data, models, and life cycle management processes as exemplars for as the basis for an effective DEAE and acquisition process.

11. Building on the example of effective and efficient data transfer between R&M and PSM, as well as Intel, explore independent modification of Test and Evaluation (T&E), and Cost Estimating, to achieve the same data transfer efficiencies within their activities.

12. Within the acquisition activities, there are additional checks that can be invoked, and can be made more effective with a digital transformation of acquisition. Examine ITRA, and IAPR processes for the potential of strengthening the effectiveness of these processes for the PM.

13. There is a knowledge gap for those PMs experienced with MCA when moving to other pathways; as well as a knowledge gap for those new PMs who have no experience to draw on regardless of the pathway chosen. Construct a PM guide which focuses on the digital management of a program, integrating all the necessary staff functions for a PMO through data, beginning with the items in the DAVE repository.

14. The DoD needs ways and means to drive digitally transformed acquisition and sustainment adoption into Program Offices and other related government functions. Articulate the elements which are not traditionally considered by program offices in cost estimating; but are necessarily to achieve digital acquisition and sustainment.

15. OUSD(A&S) will benefit from testimonials, et al, of DE-enabled programs, or program elements. Develop interview questions to elicit shareable information from programs, and conduct interviews to refine the questions, in order to develop a dataset suitable for reference (digitally) by programs desiring to perform DE-enabled acquisition and sustainment.

References

https://www.acquisition.gov/far/part-7

2018-Digital-Engineering-Strategy (cto.mil)

Blackburn, M. R., J. Dzielski, R. Peak, S. Cimtalay, T. Fields, W. Stock, S. Panchal, J. Sisavath, G. Rizzo, Transforming Systems Engineering through Model-Centric Engineering, Final Technical Report SERC-2021-TR-012, WRT1036 (NAVAIR), August 3, 2021.

Blackburn, M. R., M. A. Bone, J. Dzielski, B. Kruse, R. Peak, S. Cimtalay, M. Ballard, A. Baker, A. Carnevale, W. Stock, A. Ramaswamy, M. Szostak, G. Rizzo, W. Rouse, D. Rhodes, M. Austin, M. Coelho, Transforming Systems Engineering through Model-Centric Engineering, Final Technical Report SERC-2020-TR-009, WRT1008 (NAVAIR), June 20, 2020.

Blackburn, M., R., M. A. Bone, J. Dzielski, B. Kruse, R. Peak, S. Edwards, A. Baker, M. Ballard, M. Austin, M. Coelho, D. Rhodes, B. Smith, Transforming Systems Engineering through Model-Centric Engineering, Final Technical Report SERC-2019-TR-103, RT-195 (NAVAIR), May 28, 2019.

CMU/SEI-2021-SR-035, Guidance for Tailoring DoD Request for Proposals (RFPs) to Include Modeling, April 2022. DOI: 10.1184/R1/16602341.

DAU, A Guide to Program Management Business Processes 2022, https://www.dau.edu/pdfviewer?Guidebooks/DAG/A-Guide-to-DoD-Program-Management-Business-Processes.pdf

DAU, A Guide to Program Management Knowledge, Skills and Practices 2022, https://www.dau.edu/pdfviewer?Guidebooks/DAG/A-Guide-to-Program-Management-Knowledge-Skills-and-Practices.pdf

Department of Defense Data Strategy, September 2020.

Defense Federal Acquisition Regulation Supplement (DFARS), Part 227, subparts 227.71 and 227.72.

DOD Instruction 5000.82 Acquisition of Information Technology (IT), April 21, 2020.

Hale, J., Zimmerman, P. , Guerrero, J., et al, Digital Model Based Engineeirng: Expectations, Prerequisites, and Challenges of Infusion, NASA/TM 2017-219633

NASA-HDBK-1004, NASA Digital Engineering Acquisition Framework Handbook, April 2020. https://standards.nasa.gov/sites/default/files/standards/NASA/Baseline/0/2020_04_01_nasa_hdbk_1004_approved.pdf.

International Council on Systems Engineering (INCOSE), Systems Engineering Vision 2035, https://www.incose.org/about-systems-engineering/se-vision-2035.

McDermott, T., W. Benjamin, Program Manager’s Guide to Digital and Agile Systems Engineering Process Transformation, Final Technical Report SERC-2022-TR-0092, WRT1051, September 2022.

McDermott, T., B. Mesmer, Systems Engineering Modernization Policy, Practice, and Workforce Roadmaps, Final Technical Report SERC-2023-TR-0002, WRT1058, April 2023.

McDermott, T., Henderson, K., Salado, A. and Bradley, J. (2022), Digital Engineering Measures: Research and Guidance. INSIGHT, 25: 12-18. https://doi.org/10.1002/inst.12366

Moore, Geoffrey, Crossing the Chasm, Third Edition, 2013.

Office of the Deputy Assistant Secretary of Defense (Systems Engineering) [ODASD (SE)], “DAU Glossary: Digital Engineering,” Defense Acquisition University (DAU), 2017.

Office of the Department of Defense Chief Information Officer, Requirements for the Acquisition of Digital Capabilities Guidebook, February 2022.

Practical Software and Systems Measurement, DE Measurement Framework ver 1.1. https://psmsc.com/DEMeasurement.asp

Systems Engineering Plan (SEP) Outline, Version 4.