SYM-AM-23-063

Excerpt from the Proceedings

of the

Twentieth Annual Acquisition Research Symposium

Acquisition Research:
Creating Synergy for Informed Change

May 10–11, 2023

Published: April 30, 2023

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

An Integration Framework for Digital Transformation of DoD Systems Engineering and Acquisition

Dr. Kelly Alexander—is the Chief Systems Engineer at System Innovation. She has over 35 years of experience in systems engineering and project management.. As a US Department of Defense civilian, she served as the Director of Systems Engineering Policy and Program Support, Director for Common Operating Environment at HQ US Army, and spearheaded the transition of modular software into the US Army's tactical software. She also led the Army's digital transformation and modular open systems using open standards and open architectures. Dr. Alexander earned a PhD in Systems Engineering from George Washington University, master's degrees from George Washington University (Systems Engineering) and National Defense University (National Resource Strategy), and a bachelor's degree in Industrial Engineering from NC State University. [kelly.d.alexander12.ctr@mail.mil]

Tom McDermott—is the Chief Technology Officer of the Systems Engineering Research Center (SERC) and a faculty member in the School of Systems and Enterprises at Stevens Institute of Technology in Hoboken, NJ. With the SERC he develops new research strategies and is leading research on digital transformation, education, security, and artificial intelligence applications. He previously held roles as Faculty and Director of Research at Georgia Tech Research Institute and Director and Integrated Product Team Manager at Lockheed Martin. Mr. McDermott teaches system architecture, systems and critical thinking, and engineering leadership. He provides executive level consulting as a systems engineering and organizational strategy expert. He is a fellow of the International Council on Systems Engineering (INCOSE) and recently completed 3 years as INCOSE Director of Strategic Integration. [tmcdermo@stevens.edu]

Abstract

This paper presents the results of a Systems Engineering Research Center (SERC) research task entitled "Program Managers Guide to Digital and Agile Systems Engineering Process Transformation." This research task supports a larger set of DoD activities being led by OUSD/RE under the term "Systems Engineering Modernization" (SEMOD). The motivation for SEMOD stems from the need to integrate across independent guidance provided down to the DoD SE and acquisition communities related to Digital Engineering, Modular Open Systems Approach, Mission Engineering, and Software Engineering/ Agile/ DevOps across the multiple pathways of the Adaptive Acquisition Framework. The SERC/government research team found there is a lack of an integrated approach to implementation of SE Focus Areas that is creating a delay in full implementation of the Digital Transformation, which is necessary to ensure the relevant guidance, skills, and training, are available to deliver a robust, disciplined approach to weapon systems acquisition.

Introduction

The research conceptualized an integration framework that has at its core "shared and authoritatively managed data" that can be transformed through various models and tools to create Digital Artifacts. These artifacts are used by various decision makers and others needing digital access to the design and descriptions of the system across its life cycle. In early years, these artifacts were usually paper documents or drawings, now they are mostly based on digital technologies but far from "seamlessly integrated and interoperable."

As the research team developed the integration framework, we came to realize first that existing SE mostly linear lifecycle depictions like the "Vee" model and the DoD's "Defense Acquisition Wall Chart" do not promote the future vision of data and models at the core of SE and acquisition. Secondly, since future systems will be "built for change" using concepts of continuous iterative development, do the somewhat linear models of existing SE lifecycle representations still adequately guide us? In response, the team shifted to developing a new conceptual view of the full SE Modernization Lifecycle, which we called the Supra-system

Model. This view depicts all acquisition pathways as continuous processes with data at the core, models as the decision tools, and SE lifecycle processes as the decision points (and artifacts).

First, the research redefines systems engineering as a cyclic approach, rather than a linear one. Although almost all literature attempting to standardize on a lifecycle model will say that activities are ongoing and should continue through the lifecycle, the current Vee model does not reflect the iterative nature of today's systems and capabilities.

Second, the integration framework clearly shows that an acquisition program can enter the lifecycle at any point, and integrates across all six acquisition pathways of the Adaptive Acquisition Framework.

Third, this integration framework makes the digital transformation clear using a layered model with data storage and transformation at the core, models as the data transformation layer, and systems engineering process areas as the outer layers.

SE Modernization Integration Framework

Program managers today are facing a myriad of acquisition process changes centered on the need for more rapid deployment of capabilities, better weapon system portfolio management, and efficiencies created through digital transformation. There is a need for documentation of lessons learned, program best practices, and standard guidance for program Systems Engineering that incorporates a holistic approach inclusive of the four SE Modernization focus areas, the six acquisition pathways, and the digital transformation outlined in the DoD Data Strategy.

In this project, we first attempted to derive a framework to integrate across all aspects of future systems engineering by analyzing the text from current SE-related SE standards and the independent DoD guidance from each of these change areas. We found that existing DoD and SE process guidance did not capture the relationships across these focus areas of SE Modernization. We also recognized that systems engineering guidance still retains its historical alignment with Major Capability Acquisition (formerly Major Defense Acquisition Programs (MDAP))and has not become integral with other system approaches such as innovation and prototyping, agile software development, business and service systems, and data-connected systems. We found that we had to step away from history and visualize a new set of mental models to guide the practice of systems engineering in future DoD uses. This report starts with a historical view of SE in DoD acquisition activities, discusses the imperatives driving a modernized view, places SE in the digital transformation of all engineering and acquisition, then proposes "The Supra-System Model" as a revised mental model that integrates across all engineering and acquisition activities, and possibly beyond acquisition into other activities that benefit from modernized, digitally transformed SE.

SE has long been integral to DoD Acquisition Processes

Systems engineering principles and methods were adopted by the DoD in the late 1960's/early 1970's as a way to manage technical and programmatic development and risk across the engineering and management components of large complex weapon systems. The DoD published Military Standard 499A, Systems Engineering Management, in 1969. When the first iteration of DoD 5000.01 "The Defense Acquisition System" (DAS) was published in 1971, it defined a systems engineering related set of guidance including consideration for problem/operational needs, alternatives, test and evaluation, and support and update. It also introduced related management activities such as contracting, risk, source selection, and documentation. Mil-Std-499B was introduced in 1992 but was never published, as military standards were cancelled in the early 1990's as part of DoD acquisition reform initiatives. The majority of the concepts in Mil-Std-499B were incorporated into the Defense Acquisition University (DAU) Systems Engineering Fundamentals handbook in 2001. This contained a graphical SE lifecycle process description as well as the now familiar milestone driven acquisition process shown in Figure 1.

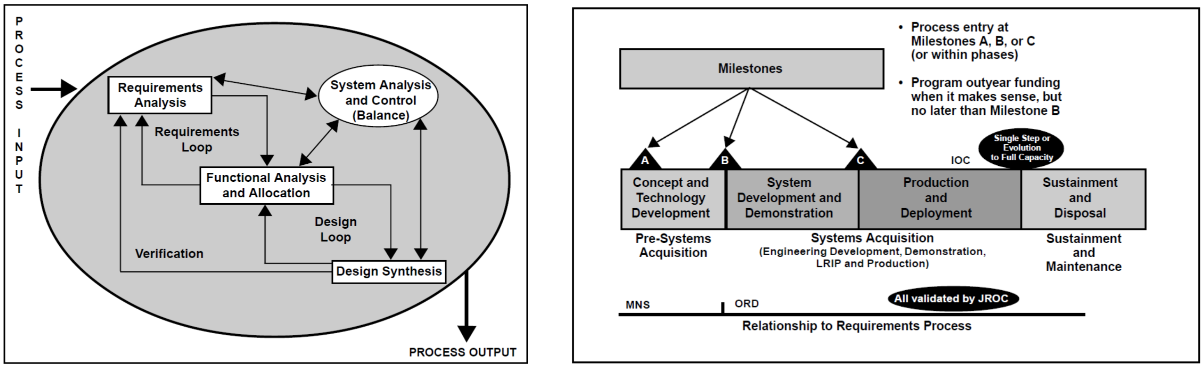

Figure 1. Initial DoD SE Process Model and acquisition process flow (DAU SE Fundamentals 2001)

The concept of the V-model was developed simultaneously, but independently, in Germany and in the United States in the late 1980s. It has been used interchangeably to represent 1) the concept of decomposition/synthesis of a systems development into different levels of functional definition, realization, and test (Figure 2); and 2) an SE technical and management process model (Figure 3).

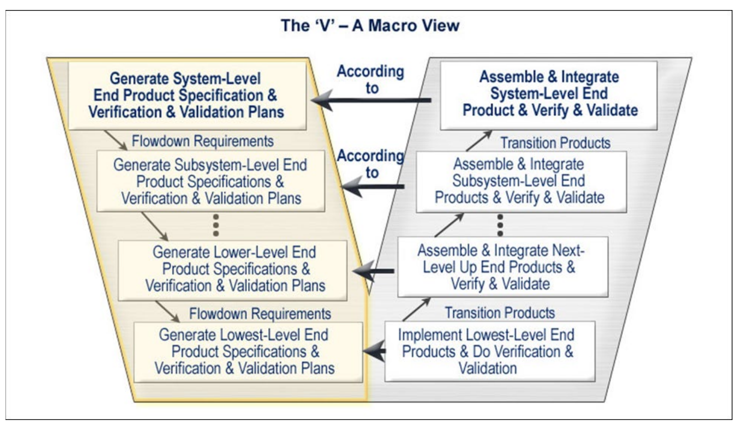

Figure 2. The Vee-model as a functional decomposition/synthesis process (INCOSE SEBOK)

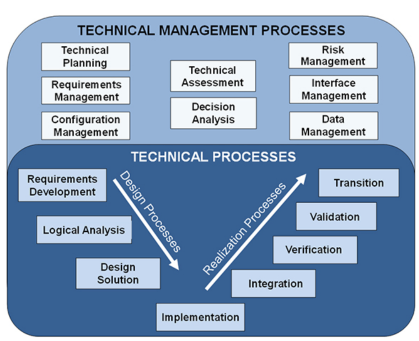

Figure 3. Revised SE Process Models of 2003 in the DAU Acquisition Encyclopedia, using the Vee-model to as a set of technical processes. https://www.dau.edu/acquipedia.

The current DAU documentation of the Vee-model generalizes and combines these two perspectives, as shown in Figure 4. The current acquisition model for MDAPs, now known as Major Capability Acquisitions (MCA) is shown in Figure 5. The current DoD SE Guidebook does not show an equivalent technical review process for the other AAF acquisition pathways. However, each of the pathways does provide some lifecycle guidance and guidance on tailoring reviews and audits (https://aaf.dau.edu/aaf/aaf-pathways/).

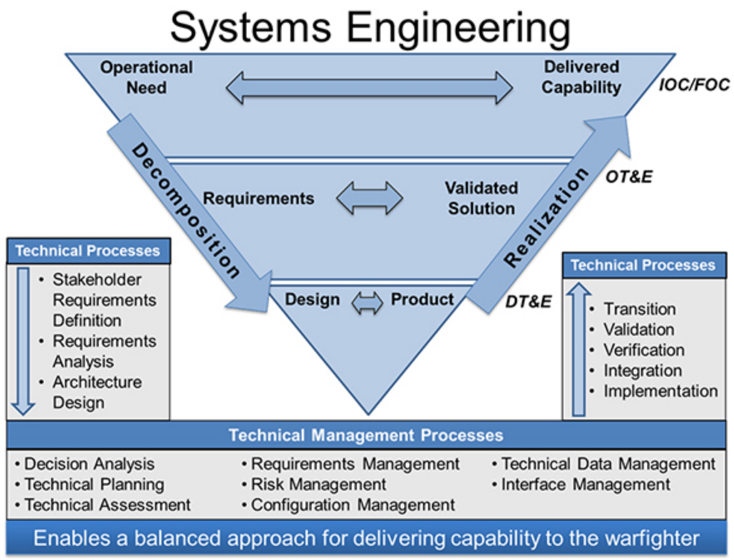

Figure 4. Current DoD SE Processes (DoD SE Guidebook 2022)

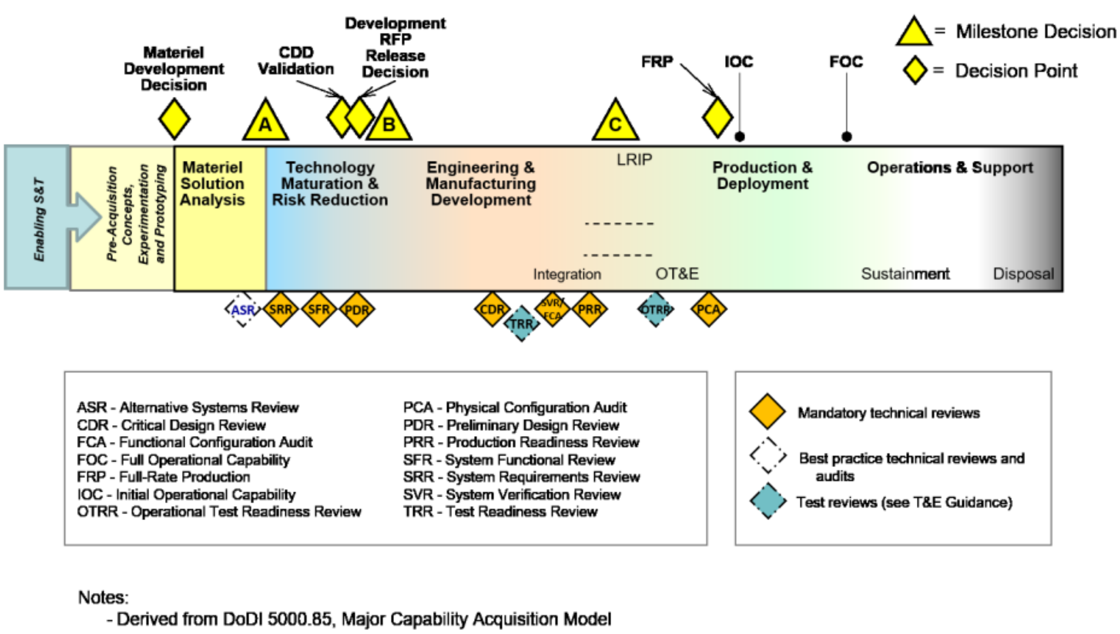

Figure 5. Technical Reviews and Audits for the MCA Life Cycle (DoD SE Guidebook 2022)

The discipline and its use in DoD acquisition has long been associated with realization of physical systems and related equipment, in Major Defense Acquisition Programs (MDAP). These figures are shown to highlight how “mental models” of SE have been codified into DoD acquisition for over 50 years. Meanwhile SE has grown to a much broader discipline, impacting software systems, business systems, manufacturing systems, innovation systems, enterprise systems, and other system types used by the DoD. Many of these applications have developed their own lifecycle process models in response to this traditional SE literature and related use, viewing “traditional SE” as slow and non-responsive to change.

Why SE Modernization?

Today many defense capabilities are not only physical; they are software intensive, highly connected, and have extensive automation and user configuration capabilities. Software engineering became a discipline in 1967, manufacturing automation (the third industrial revolution) began in the 1970's, and the World-Wide-Web was invented in 1989. The DoD's Defense Modeling and Simulation Office was opened in the early 1990's and large-scale networked simulation of defense systems followed. All of these have continued to evolve the SE discipline, not as a whole, but as a set of related sub disciplines (systems engineering, software systems engineering, information technology and enterprise architecture, distributed modeling & simulation, and automated manufacturing systems). **It is notable that each of these sub disciplines views lifecycle process and technical review as something that is much more iterative than what is implied by current SE guidance.**

Following successful evolution of the Unified Modeling Language (UML) in the software discipline, the Systems Modeling Language (SysML) was published in 2007 and started the growth in Model-Based Systems Engineering (MBSE) as an improved approach to manage technical and programmatic risk. "Industry 4.0" originated in 2011 and introduced the concept of a "digital twin" as a non-physical product realization. The DoD's Digital Engineering (DE) Strategy was published in 2018, ushering in the vision of a digital era of systems engineering. As the International Council on Systems Engineering noted in their Vision 2035 document: "The future of Systems Engineering is Model Based, leveraging next generation modeling, simulation and visualization environments powered by the global digital transformation, to specify, analyze, design, and verify systems."

Throughout all of this change, the primary use 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. The need for rigorous definition, analysis and test of these critical systems will always exist; and the time has come to integrate the systems engineering sub disciplines into a common framework that responds to the digital age. A further SE vision statement might read: “the future of SE is more iterative and responsive to user needs.” Future SE discipline needs to be more model-based and more agile and responsive, which will be accomplished with more efficient lifecycle processes.

SE Modernization Focus Areas

In FY2021, the SERC was tasked by the DoD to conceptualize and build an integration framework for SE Modernization as applied to all DoD acquisition life cycles. Between 2019 and 2021, the DoD published its latest 5000 series guidance, "The Adaptive Acquisition Framework" in 2021 to show the various development and acquisition pathways for software (2020), IT and business systems (2020), services (2020), and a streamlined "middle tier" acquisition (2019) for more mature rapidly fielded systems. This followed a series of legislative directions to the DoD four focus areas for SE Modernization as defined below:

1. **Digital Engineering (DE)** – Defined in the DoD DE Strategy as "an integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support lifecycle activities from concept through disposal." As directed in DoD policy, "DE will provide for the development, validation, use, curation, and maintenance of technically accurate digital systems, models of systems, subsystems, and their components, at the appropriate level of fidelity to ensure that test activities adequately simulate the environment in which a system will be deployed."
2. **Modular Open Systems Approach (MOSA)** – Defined in DoD policy as "an acquisition and design strategy consisting of a technical architecture that adopts open standards and supports a modular, loosely coupled and highly cohesive system structure." This modular open systems approach includes publishing of key interfaces within the system and relevant design disclosure. MOSA introduces the 'build for change, not to last' philosophy from software architecture across all aspects of DoD systems.
3. **Mission Engineering (ME)** – Defined in DoD guidance as "the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired mission effects. Mission Engineering is intended to provide engineered mission-based outputs to the requirements process, guide prototypes, provide design options, and inform investment decisions."
4. **Agile Development** – Defined in DoD guidance as "approaches based on iterative development, frequent inspection and adaptation, and incremental deliveries, in which requirements and solutions evolve through collaboration in cross-functional teams and through continuous stakeholder feedback. Agile approaches begin not with detailed requirements, but with a high-level capture of business and technical needs that provides enough information to define the software solution space, while also considering associated quality needs (such as security)." Note that agile does not have to be software specific, and the principles can apply to any process.

In addition, the **DoD Data Strategy** (2020) emphasizes data as a strategic asset, collective data stewardship, data collection, enterprise-wide data access and availability, data fit for purpose, and design for compliance. At this point the SE community may be overly focused on "System Models" and underly focused on "System Data" in the Digital Engineering Strategy. As outlined in the SERC the Digital Engineering Competency Framework (DECF) project, data architecture, data standards, data governance, and talent and culture are all essential components of SE Modernization and may be new concepts to systems engineers (DECF 2020, DECF 2021).

The four focus areas can be viewed as a layered model with a data strategy at the core, as shown in Figure 6. At the center, as envisioned by the DoD Digital Engineering strategy, is shared and authoritatively managed data. Modernization of systems engineering strives for seamless interoperability and integration of all engineering and management disciplines using authoritative sources of system data and models as the continuum that links the disciplines.

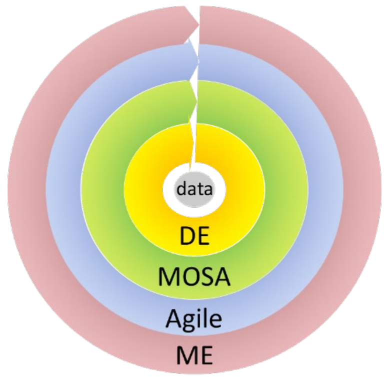

Figure 6. Four focus areas as a layered model
(Cleared for public release DOPSR Case # 23-S-0026)

It should be noted across these focus areas that DE and ME aligns to “the future of SE is model-based” while MOSA and Agile align to “the future of SE is more iterative and responsive to user needs.” These are not at odds, as appropriate use of models provides the foundation for iterative learning. **Fundamentally, modernization of SE lifecycle processes must define how data and models are used to be more iterative and responsive to user needs.** In this project we found that is not the mental model or vision of current policy and guidance related to these focus areas. our SE Modernization vision is stated below:

The vision of SE Modernization is to use data and models to create a more agile and responsive acquisition system that can quickly and effectively meet the needs of the warfighter.

Digital Transformation of Systems Engineering

At the core of SE Modernization is "shared and authoritatively managed data" that can be transformed through various models and tools to create Digital Artifacts. These artifacts are used by various decision makers (in development) and others needing digital access to the design and descriptions of the system across its life cycle. In early years these artifacts were almost always paper documents or drawings, now they based on digital technologies but far from "seamlessly integrated and interoperable." The cartoon in Figure 7 might best describe the current state of digital artifact development.

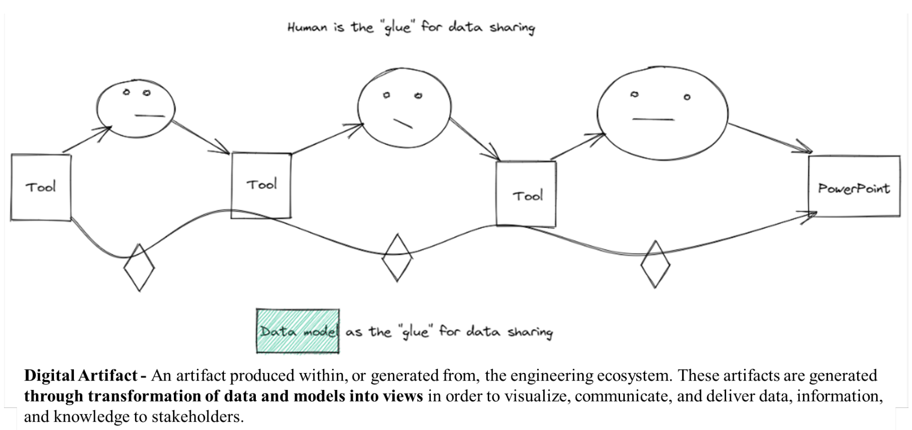

Figure 7. Data Transformation Mental Model
(Cleared for public release DOPSR Case # 23-S-0026)

Systems engineers have long used digital data and various modeling and analysis tools to produce digital artifacts for decision-making. However, the underlying data model has not been "seamlessly shared", and likely not shared at all, and authority for that data has been held by independent activities, generally organized by discipline. Much of the "transformation" is still manual interpretation of disparate data and analyses. This manual interpretation limits our ability to be iterative and responsive across disciplines and disciplinary tools. One might describe the current state of systems engineering as seeing the whole while looking through a set of soda straws. We desire a fully integrated, iterative workflow where the system is the focus, not the owner of the data, or the particular element of a design. Today's primary challenge in digital engineering is not so much being "model-based," it is understanding and creating the underlying data model that integrates across requirements, design, and test, and across disciplines and disciplinary processes, and is shareable and shared.

This leads us to the **value statement** for SE Modernization, depicted in Figure 8 and the box below:

The value of SE Modernization will be realized in more seamless and efficient transfer of data and models from underlying performance drivers through models to decisions, as well as ease of drilling back down from decisions to data.

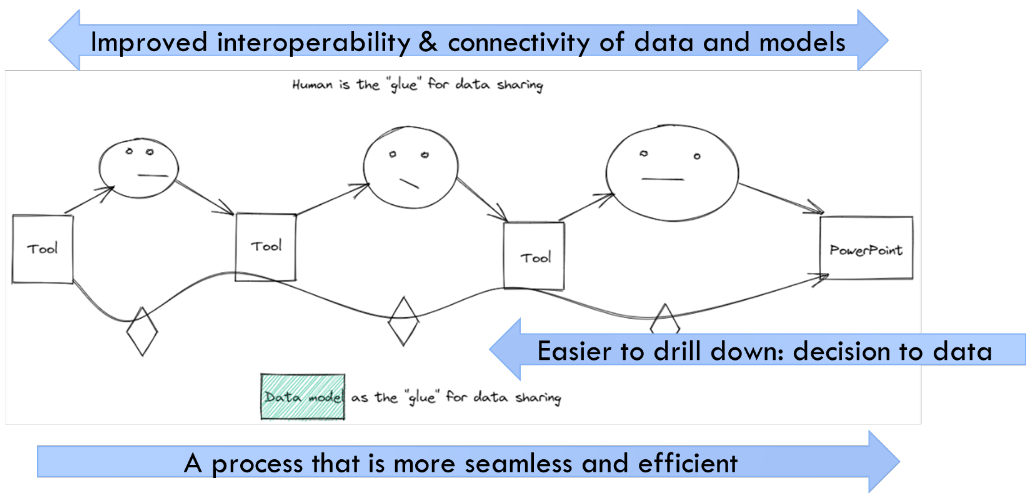

Figure 8. SE Modernization Value Depiction
(Cleared for public release DOPSR Case # 23-S-0026)

Systems engineering and related acquisition processes can be visualized as a set of iterative data transformations from sources of truth that produce artifacts for human consumption – across all stages of a system life cycle.

Figure 9 redraws the widely depicted Define->Realize->Deploy&Use stages of the SE Vee-model in a circular process to represent it as a:

1) set of data transformations at the core;
2) layered across disciplines & tasks;
3) in continuous iterative processes that could be entered from any point.

In the figure we generalize define, realize, and deploy as a "Learn->Build->Measure" to be more consistent with current design literature.

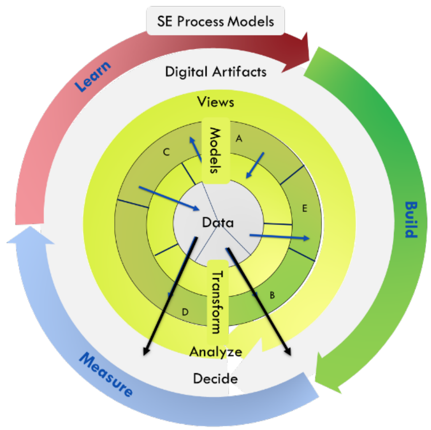

Figure 9. Circular Processes with Data at the Core
(Cleared for public release DOPSR Case # 23-S-0026)

In SE technical and management processes, data is transformed through models into views, which support analyses leading to decisions. These transformations have traditionally produced decision artifacts that were severed from the underlying data and models and captured in independent static document or presentation forms. Digital artifacts may still be documents or presentable views but should remain digitally connected to the underlying data and models from which they draw context and "explainability". This process flow reflects "Data Transformed into Models then Analyzed through Views to make Decisions documented in Digital Artifacts." This process flow has been the core of SE technical and management processes within each lifecycle phase since the inception of SE. It has largely been a manual, inefficient process flow that focused on "presentability" rather than context.

SE lifecycle processes as defined by ISO/IEC/IEEE 15288 do not define a specific ordering of process areas, but much of the literature and existing mental models imply a process ordering that is started in the learn (define) stages. SE lifecycle processes have been used not just in critical systems where up-front system definition and learning are essential, but also in process and system innovation, prototyping, and incremental definition activities where build-first is the pathway to learning; and in sustainment life cycles where deployed system measurement and learning should be applicable to both the system sustainment, but also to define the next build. This SEMOD circular mental model better recognizes that SE technical and management processes can be applied to any life cycle in any type of system. Figure 10 visualizes the domains of SE in association with the ordering of learn, build, and measure cycles.

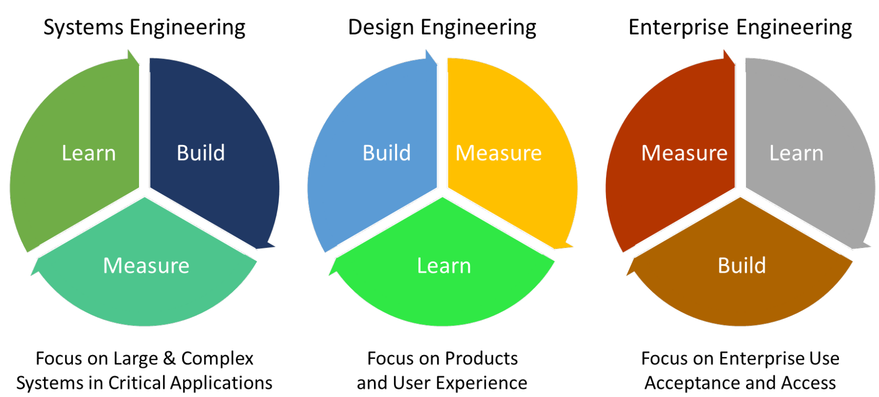

Figure 10. Different lifecycle ordering in different applications of SE

The DoD published the Adaptive Acquisition Framework (AAF) in 2019 (Figure 11). Between 2019 and 2021, the AAF recognized new development and acquisition pathways for software, IT and business systems, services, and a streamlined "middle tier" acquisition for more mature rapidly fielded systems. In the AAF, the Major Capability Acquisition pathway continues the traditional use of upfront SE rigor and its rigorous Learn->Build->Measure cycle and remains as the most known of the acquisition pathways. However, the Urgent Capability, Middle Tier, and Software Acquisition pathways promote an abbreviated definition phase and rapid learning through builds; following SE processes developed in the engineering design and software development fields. The Defense Business Systems and Acquisition of Services pathways are more aligned with the Enterprise Engineering. The challenge of SE Modernization is to maintain appropriate SE rigor and associated process definition in all pathways. **SE rigor is maintained using the data –>transform–> analyze–>decide flow of Figure 9, not through a specific ordering of SE processes**.

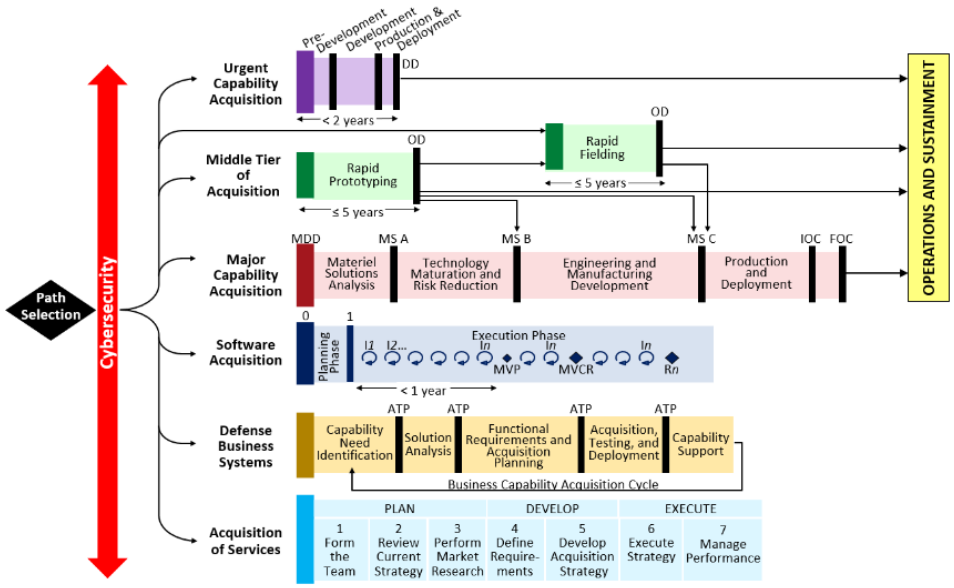

Figure 11. The Adaptive Acquisition Framework (aaf.dau.edu)

The workflow view in Figure 12 shows conceptually how shared and authoritatively managed data is transformed into digital artifacts in different life cycle stages in any pathway. This linear workflow model is familiar and comfortable to system engineers but does not represent the fact that these data transformations into and out of the shared and authoritatively managed federations of data and models actually happen iteratively and continuously across a life cycle. **Increasing responsiveness to the warfighter (or market) does not mean eliminating these critical SE processes, just increasing the number of iterations and shortening the cycle time between them.**

This figure also highlights how the broadly published goal of the DoD Digital Engineering Strategy "Provide an enduring authoritative source of truth" may be misleading to the DoD program management communities. In reality, the "source of truth" will be a distributed federation of data and models. The goal should be revised to "Create govern and use a set of authoritative data and models in order to share knowledge and resources across the system lifecycle." These data and models might originate in any phase of a systems lifecycle and in any function associated with DoD engineering and acquisition. In fact this will always be the case. "Who owns the data and models" remains a pain point in this transformation.

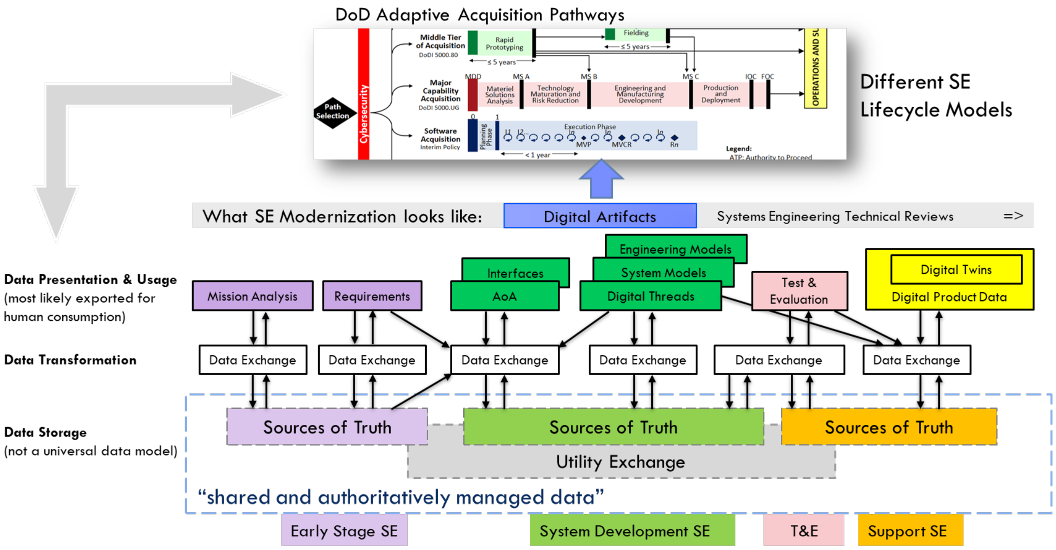

Figure 12. Data Transformation into the Life Cycle

This figure is particularly relevant to SE modernization, as "Data Management" is not currently defined as a disciplinary process in SE standards or DoD engineering policy. Data models and data storage systems are separate systems that must also be developed and deployed in support of the fielded system. These must be defined and built along with other aspects of a systems development. Data engineering and data modeling do follow SE processes but require different disciplinary skills than physical systems.

This leads us to the "roots" of the **integration framework** for SE Modernization, which must address how shared and authoritatively managed data and models are defined, built, deployed, and used in DoD systems:

New SE lifecycle processes must address shared and authoritatively managed sets of digital data and models associated with the full lifecycle of the system itself, not single acquisition program lifecycle.

We found in our interviews and workshops on this project, the terms data, digital models, digital artifacts, digital threads, and virtual systems or "digital twins", all have different definitions, uses, and driving forces behind their lifecycles. They are not being viewed in an integrated set of lifecycle and process models. In this research, we developed a more integrative view of an SE lifecycle model that we call "The Supra-System Model." This mental model was created to be a discussion tool to distinguish historical SE lifecycle and process models from a modernized approach needed to support today's activities and systems.

The Supra-System Model: Evolving the SE Modernization Framework

This discussion begins with background from an abbreviated literature review. Thullier and Wippler in their chapter "Finding the Right Problem" from the book Complex Systems and Systems of Systems Engineering caution us to always consider three lifecycles associated with any system, each with interdependencies and relative positions in the evolution of a system (Thullier and Wippler 2013):

- "*the system lifecycle*: the "experiences" of the system itself;
- *the program lifecycle* of the system: the rhythm of the project during study, development, production, etc. of the system;

- *the engineering cycle*: the processes and activities involved in engineering the system."

Historical SE literature tends to portray these different lifecycles as simultaneous, and combined into a disciplinary framework known as the SE Lifecycle. This may have been appropriate when most SE activities were focused on large-scale physical systems, but with wider application of SE they have become more distinct and separated in their purpose.

It is important to note that there are two established definitions of the term "Lifecycle" (Merriam-Webster):

1. "the series of stages in form and functional activity through which an organism passes between successive recurrences of a specified primary stage" (multi-generational)
2. "a series of stages through which something (such as an individual, culture, or manufactured product) passes during its lifetime." (single generational)

Systems Engineering and the "Systems Lifecycle" as defined by ISO/IEC/IEEE 15288:2015 and the Project Management Institute's (PMI) project lifecycle tend to follow the second definition. Design Engineering, Software Engineering, and Enterprise Engineering models tend to match the first definition better.

ISO/IEC/IEEE 15288:2105 defines a set of process descriptions for describing the lifecycle of systems as both an engineering cycle and a project lifecycle viewpoint. In other words, the Vee-Model representation of SE standards and DoD Acquisition guidance reflects a single pass through engineering and program lifecycle activities but the actual system lifecycle, the "experiences of the system itself," will progress through a number of such engineering and program lifecycles.

Thullier and Wippler note that in the lifecycle of the system itself the "experience of the system" must be evaluated in periods and across levels of temporal or time invariance. In their description the lifecycle a system progresses (experiences its life) from idea; to a virtual existence in models, documents, software, and today many digital artifacts; then to a physical existence. SE technical and management process divides these into stages. SE processes recognize "within each level [of abstraction], we may distinguish periods of time which we may observe the integrity of the structure and behavior of the system [as invariant]." We may use these periods to enable interdisciplinary and collaborative activities, referred to as phase gates or decision points. Virtual artifacts by their nature can cycle through more rapid periods of change than physical artifacts (Thullier and Wippler 2013).

Thullier and Wippler also note that program lifecycle phases "are aligned (or mixed in) with key steps (or stages) of the system lifecycle. This allows us to fix program phases on integrated, coherent, and stable states of the system in question, and thus to make important decisions at precise moments in the life of the system." They further note that the engineering lifecycle is: "the process that consists of moving from need…to an optimized solution – i.e. the best compromise integrating all constraints (cost/ time/performance) for the entirety of the phases and situations involved in the system lifecycle...This should not, however, be taken to mean that these processes must be carried out in a sequential manner" (Thullier and Wippler 2013). In other words, the idea that the system lifecycle, the program lifecycle, and engineering lifecycles can be combined together is a fallacy. There are "periods of temporal invariance" where we can view these lifecycles together in order to make important decisions, otherwise they should be considered as independent. **Trying to force them to remain in lockstep limits our ability to be iterative and responsive.**

It is important to note that systems engineering lifecycles and processes are not new, they have just evolved in different ways since first envisioned in the 1960's. Stanley Shinners in the 1967 book "Techniques of Systems Engineering" first introduced the concept of SE as the methodological approach to define, realize, and deploy a system inherent in today's SE lifecycle processes. Shinners defined the general techniques of SE that exist today: understand the problem, consider alternative solutions, choose the most optimum design, synthesize the system, test the system, compare test results with requirements and objectives, and update the system characteristics and data. This early process flow represents the basis for SE as the "technical and management driven systems oriented problem-solving process" that permeates much of the SE literature and DoD practice today (Shinners 1967). It also is the basis of software DevOps practice. This "systems engineering rigor" should not be changed but must be applied to all systems, both virtual and physical, in any program management lifecycle. What is changing today with the advance of digital computing is how we maintain SE rigor using the modernized data –>transform–>analyze–>decide flow referred to in Figure 9.

Finally, Arthur David Hall in A Methodology for Systems Engineering (1962) stated that SE must consider the environment the system enters into: "the environment is the set of all objects outside the system: (1) a change in whose attributes affect the system and (2) whose attributes are changed by the behavior of the system." Thus, we cannot bound the system away from its external environment but must consider the experience of the system to be affected both by the technical and management processes that evolve the system and the external situations that seek to adapt the system. Ludwig von Bertalanffy in General Systems Theory (1968) noted that systems can be divided according to levels of complexity into systems, supra-systems, and subsystems. The different levels interact and are not independent of each other. While engineering lifecycle should be interested in decomposition of system into subsystems, the system itself should not be managed independently from its supra-system. The program lifecycle should ideally consider both subsystem and supra-system interdependencies.

The Supra-System Model: the SE Modernization Mental Model

Thus, four individual lifecycles may affect the "experience of the system." These must be distinguished if we want an SE process model that reflects any acquisition pathway with the SE rigor we have been accustomed to in historical SE and acquisition lifecycle process models. One is the lifecycle of the system itself and potentially of the offspring; it produces (both aspects of the lifecycle definition). Two others are the engineering and program or project lifecycles, which conduct processes internal to the life of the system. Finally, is what we call the "supra-system" lifecycle, which reflects the direct experiences of the system itself in its operational context as related to the closest other systems it interacts with; A supra-system is defined is a larger system that integrates or contains other systems.

In addition to recognizing that each of the four lifecycle/process models may be individually relevant; the roots of our integration framework of Figure 9 require that each of these lifecycle processes must evolve to address shared and authoritatively managed sets of digital data and models associated with the full lifecycle of the system itself, not just a single acquisition program lifecycle. Much of this data is contextual data in the supra-system. The established DoD views that combine management processes/lifecycle and technical processes/lifecycle do not fit well into the circular data-oriented mental model: technical (engineering) iterations and management (program) iterations have very different decision processes and respond to different types of data, with some content overlap. Furthermore, SE is a holistic or systems-oriented problem solving approach that reflects both the system and the supra-system. These are visualized together in Figure 13.

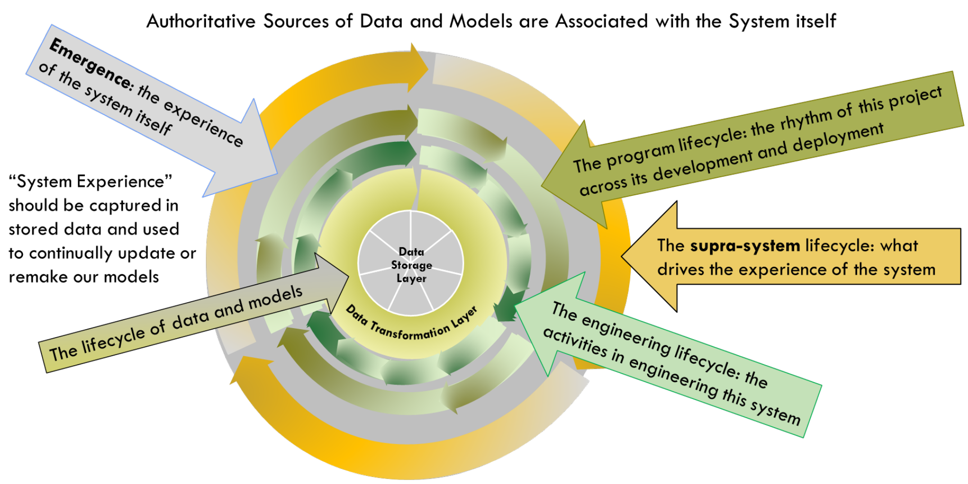

Figure 13. Multiple lifecycles of interest centered on data and models

To reflect fully the model of Figure 13, the team shifted to developing a new conceptual view of the full SE Modernization Lifecycle, shown in Figure 14. This is the Supra-system model. This view is an attempt to capture everything associated with DoD engineering and acquisition activities in one mental model. It must be tailored and redrawn based on differing types of development, delivery, and support processes. This view is complex, but with study, it becomes insightful in several ways. First, it illustrates systems engineering as a cyclic approach, rather than a linear one. Although almost all literature attempting to standardize on a lifecycle model will say that activities are ongoing and should continue through the lifecycle, the circular illustration drives this point home more visually and directly.

Second, it captures the view that the "experience of the system itself" is a continuous journey that could be affected by multiple external supra-system evolutions, multiple program cycles, and multiple engineering cycles.

Third, this integration framework makes the digital transformation clear using a layered model with data storage and transformation at the core, models as the data transformation layer, and systems engineering process areas as the outer layers. Data and models can be associated with any activity in the system lifecycle, and must live their lives with the full experienced life of the system, not just a single program lifecycle.

Fourth, it organizes the colors of the outer ring and related SE process in the "Build/Measure/Learn" context, capturing the underlying goal of continuous iterative development.

Finally, it recognizes that data and models may come from any experience of a system, including pre-Material Development Decision (MDD), post Operational Test and deployment and support. In particular, mission engineering and operational test and evaluation activities explicitly learn and measure relationships between the system and supra-system and produce data that should be retained to inform other activities across the full SE Modernization lifecycle.

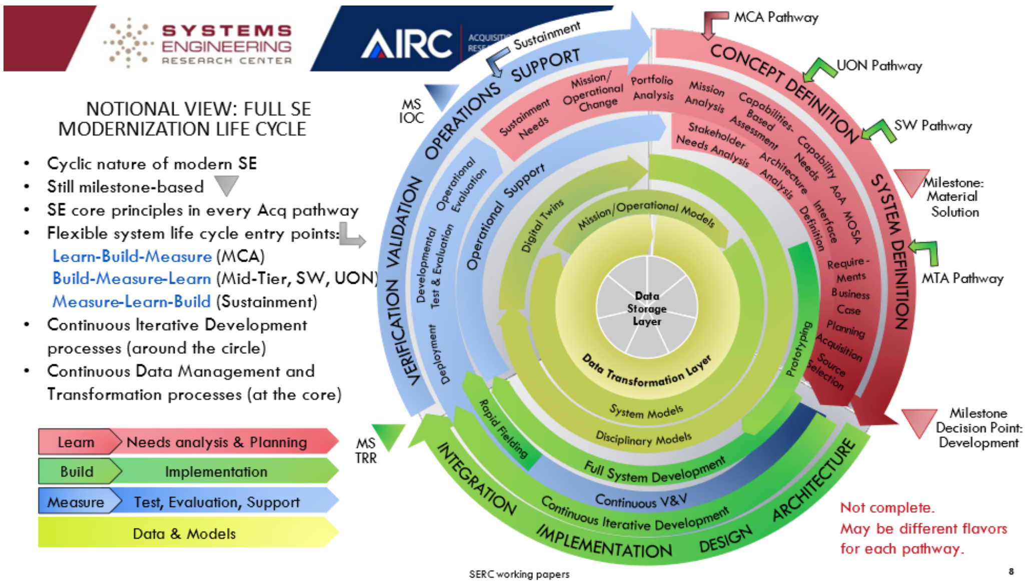

Figure 14. The Supra-system Model
(Cleared for public release DOPSR Case # 23-S-0026)

The integration framework depicted here incorporates traditional DoD acquisition milestones (triangles). However, it highlights them in the context of the multi-faceted work going on and where they fall within the broader context. It highlights the different DoD acquisition pathways and associate SE process instantiations. These fundamentally begin at different points in the system life cycle but should still follow a rigorous SE process model.

Summary and Use

This research found:

"**The value of SE Modernization will be realized in more seamless and efficient transfer of data and models from underlying performance drivers through models to decisions, as well as ease of drilling back down from decisions to data**."

And:

"**New SE lifecycle processes must evolve that address shared and authoritatively managed sets of digital data and models associated with the full lifecycle of the system itself, not just a single acquisition program lifecycle**."

In addition, newer systems engineering sub disciplines like software systems engineering, information technology and enterprise architecture, distributed modeling & simulation, and automated manufacturing systems "view lifecycle process and technical review as something that is much more iterative than what is implied by current SE guidance." This research found that the mission of SE Modernization, contrary to much of the published "future of SE" literature, should focus less on models and more on "increasing responsiveness," by promoting lifecycle processes that "increase the number of iterations and shorten the cycle time between them." This led to our vision statement:

"**The vision of SE Modernization is to use data and models to create a more agile and responsive acquisition system that can quickly and effectively meet the needs of the warfighter**."

Additionally, this research found that data management has become a necessary systems engineering process area for today's systems and enterprises, and this needs to be added to SE lifecycle process standards and associated education and training.

Finally, the research found that current literature does not distinguish between system, program, engineering, and supra-system lifecycle processes and current acquisition guidance often "forces them to remain in lockstep which limits our ability to be iterative and responsive." Acquisition processes should provide more flexibility to the systems engineering community in how they use SE lifecycle processes, and acquisition pathways in the AAF should provide more guidance on the use of SE in each pathway.

This discussion is not a call to change the whole Defense Acquisition System to a new model. It defines a framework that hopefully better integrates across all defense acquisition activities including those that exist outside of an approved material development program. It also tries to place systems engineering in the context of any acquisition pathway. Its main purpose is to refocus the discussion on the system instead of the acquisition of the system or the development of the system, because data and models will have lifecycles that extend beyond a single program or development cycle.

References

L. von Bertalanffy, General System Theory; Foundations, Development, Applications. New York: G. Braziller, 1969.

DAU Acquisition Encyclopedia, https://www.dau.edu/acquipedia

DAU Systems Engineering Fundamentals, DAU Press, January 2001.

Office of the Deputy Director for Engineering, Office of the Under Secretary of Defense for Research and Engineering, Systems Engineering Guidebook, February 2011, https://ac.cto.mil/wp-content/uploads/2022/02/Systems-Eng-Guidebook_Feb2022-Cleared-slp.pdf

N. Geier and K. Alexander, "Systems Engineering Modernization Initiative," NDIA Systems and Mission Engineering Conference, November 2021.

A. D. Hall, A Methodology for Systems Engineering. Van Nostrand, 1962.

ISO/IEC/IEEE 15288:2015, Systems and software engineering — System life cycle processes.

T. McDermott and W. Benjamin, SERC Final Technical Report SERC-2022-TR-009, Program Managers Guide to Digital and Agile Systems Engineering Process Transformation, September 2022.

Mil-Std-499 (USAF), 17 July 1969.

Mil-Std-499A (USAF), 1 May 1974.

P. Thullier and J. Wippler, "Finding the Right Problem," in D. Luzeaux and J. Rualt, eds., Large Scale Complex Systems and Systems of Systems, ISTE, 2011.

Systems Engineering Body of Knowledge, www.sebokwiki.org.

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

www.acquisitionresearch.net