PART 2: SEMOD PAIN POINTS AND ROADMAPS

This report presents a list of and discussion of the SE Modernization Pain Points and a set of short term and long term roadmaps for further development. The pain points were developed on SERC Project WRT-1051 and have been updated slightly based on a workshop completed February 28, 2023.

The integration of all of the research on this project was used to create a comprehensive set of roadmaps for future SE Modernization development. Per the sponsor request, these roadmaps were produced in the format of other SERC research roadmaps which can be accessed at https://sercuarc.org/research-roadmaps/.

SE MODERNIZATION – PAIN POINTS

Throughout the 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 SE modernization experiences. These discussions led to a comprehensive set of pain points that were developed to inform future SE modernization roadmaps. This section presents the final pain points analysis.

OUTREACH ACTIVITIES

The research team conducted four formal workshops with government, industry and academia to gain insights. The workshops included:

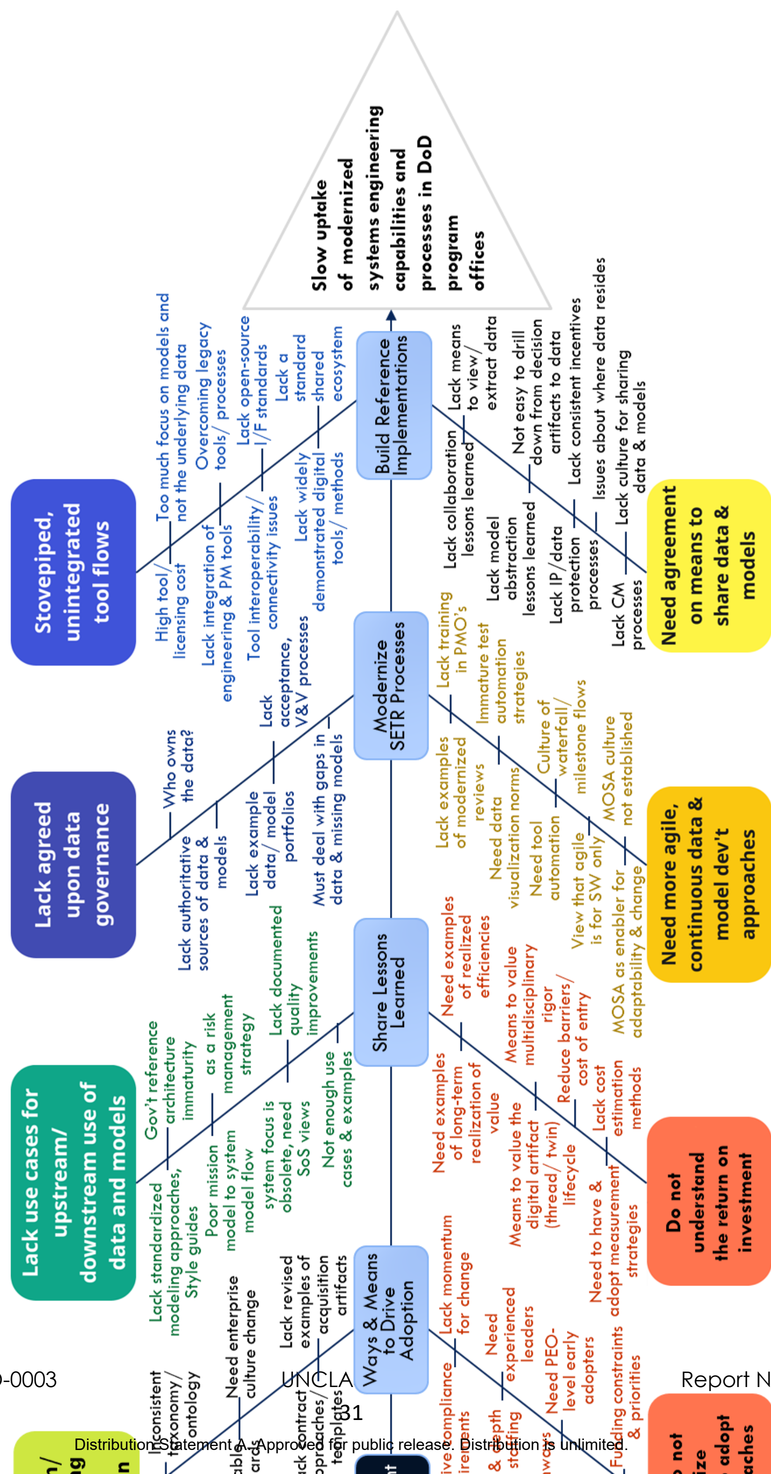
1. Translating Digital Engineering into Pragmatic Impact (November 2021)
2. SE Modernization Strategy (January and June 2021) – conducted jointly with the International Council on Systems Engineering.
3. Digital Artifact Workshop (February 2022) – conducted jointly with DAU.
4. SE Modernization Pain Points Workshop (February 2023) – conducted with government sponsors. This was a final update to review the pain points at the completion of the lessons learned analysis.

Across the project, the team also had a number of individual discussions with DoD functional area leads and system program offices in interviews that were led by the sponsor. These activities generated a number of statements that were used to inform a comprehensive set of SE Modernization pain points.

PAIN POINTS AGGREGATION

The pain points are organized into an Ishikawa (fishbone) diagram in order to provide a categorization framework and a rough ordering of pain points and needs. The full diagram is shown in Figure 15.

Figure 15. SE Mod Pain Points.



The detailed pain points in each causal path are not easily readable in the figure and will be explained further. The overall organization of the diagram represents as an input our SE Modernization value statement:

- **Seamless and efficient digital flows from data to decision artifacts and from decision artifacts back to data.**

And as an output the primary problem these pain points would address:

- **The slow implementation of modernized systems engineering processes in DoD Program Offices.**

The organization of the diagram represents four primary recommendation areas driven each by two primary aggregated pain points. These are simply categorized below:

- **Build Reference Implementations**
  - Stovepiped and unintegrated tool flows.
  - Need agreement on means to share models and data.

- **Modernize Systems Engineering Technical Review (SETR) Processes**
  - Lack agreed upon data governance.
  - Need more agile, continuous data and model development approaches.

- **Share Lessons Learned**
  - Lack use cases for upstream/downstream use of data and models.
  - Do not understand the return on investment.

- **Ways and Means to Drive Adoption (specific to DoD acquisition)**
  - Lack acquisition/engineering process integration.
  - Policies do not incentivize programs to adopt new approaches.

The detailed pain points for each recommendation area are summarized below. They have been updated and also include a set of stated stakeholder needs.

Build Reference Implementations

1. The DoD should build and share representative reference implementations that support seamless and efficient digital flows across engineering, program management, and acquisition processes. The tool, data, and model infrastructure will necessarily be tailored to the needs of the systems development. Digital tools and data/model infrastructure must exist in a combination of both acquirer and supplier tool and data/model infrastructures when contracting. Over time, standard use cases and method/tool patterns will emerge.
    a. Current tools and tool workflows are stovepiped and unintegrated. An outcome of digital systems engineering is to improve ability to collaborate across disciplines and disciplinary tools.

i. High tool/licensing cost, need enterprise level agreements and standards
ii. Today the focus is on modeling tools, need a much broader data management focus and set of processes
iii. Tools lack standard integration of engineering and program management data
iv. Tools need to support seamless and efficient ways to integrate and connect data & models
v. The community has been at this for a while, need efficient ways to transition from legacy tools/processes to the latest more capable tools
vi. Government acquirer and supplier tools and methods need to be built into a standard shared ecosystem across programs
vii. Developed and demonstrated approaches need to be widely shared across programs

Stakeholder needs:

viii. need resources: high labor and tool costs make this unaffordable for many programs
ix. need integration of engineering and program management related data
x. need better tool support to connect data and models
xi. need better ability to transition from legacy tools and models to newer tool options and versions
xii. need better acquirer/provider sharing processes in both directions

b. Need agreement across programs and across organizations on the means to share data and models and related SE practices

i. The community has not yet developed a culture for sharing data and models
ii. There is a lack of lessons learned and standard approaches to address where the data and models will reside in the digital infrastruture
iii. Effective configuration management processes need to be developed, along with intellectual property and data protection mechanisms
iv. Program managers as acquirers and their suppliers lack the incentives (voluntary or contracted) and means for sharing data & models
v. "Seamless and efficient" means ability to easily drill down from review artifacts to models to data, today's tools and methods lack the ability to easily view/extract data at different levels
vi. Need lessons learned and best practices on the appropriate fidelity of models for different decision processes
vii. Need lessons learned and best practices on how to collaborate around models and data

Stakeholder needs:

viii. need to build a culture of collaborating/sharing
ix. need effective configuration management processes for data and models
x. need to develop intellectual property management processes

xi. need to develop and apply contractual incentives to share data and models between acquirer and supplier
xii. need tool suites that provide means to view/extract data at different levels
xiii. need tools/guides that support model fidelity design for interoperability
xiv. need modeling style guidance standards/examples for different use cases
xv. need to standardize on acquirer/supplier data and model storage and access approaches

Modernize Systems Engineering Technical Review Processes

2. There is a lack of agreed upon governance for data and models across programs, organizations, disciplines, and lifecycle phases. These have traditionally been exchanged in static artifacts (many digitized) at phase completion points like technical reviews, configuration audits, and transition points between major activities. Future digital systems engineering strategies have reimagined these as living digital threads and digital twin that live alongside the realized and deployed physical systems across the full life of the virtual system. The processes to collaborate across disciplines and organizations fully within digital model-based environments are not yet mature.
    a. DoD needs to modernize their SE technical review (SETR) and collaboration processes to focus on use of data and models instead of static presentation artifacts
        i. Who owns the data? Need standard structural and process approaches
        ii. Programs lack existing authoritative sources of data & models to build from
        iii. Programs lack examples of data/model portfolios and experience in managing them
        iv. Programs lack mature processes and methods for accepting and validating data/models consistent with modern continuous development and integration methods
        v. Programs need ways to identify and manage what data/models are needed when, and experience/risk processes to manage the gaps in data and models
        vi. Programs lack updated approaches to contract for data and models in a way that encourages collaborative use

    Stakeholder needs:

        vii. need better structural and process approaches for government data/model ownership, including between government functions
        viii. need to develop and mature libraries of data and models
        ix. need good examples of data/model portfolios in program offices
        x. need processes for acceptance and validation of authoritative data and models
        xi. need better decision processes for establishing program data/model needs

    xii. need better processes to determine gaps and risks to define data/model requirements

b. PMs need to develop more agile and continuous data & model development processes
    i. A modular open systems approach (MOSA) is the enabler for both the data/model infrastructure and the product data lifecycle, this must be recognized as a necessary step to adaptability and change as built into the Engineering culture
    ii. The prevailing view of agile as a software development approach must be overcome, and used to change the prevailing view of development as a set of waterfall milestones
    iii. Both programs and tool infrastructures lack standards and norms for visualizing digital data and models in reviews
    iv. Programs lack examples of modernized technical and management reviews
    v. Program offices lack training on how to execute modernized SE processes
    vi. Efficiency will come from automation, need tool automation and especially model-based evaluation and test strategies

Stakeholder needs:
    vii. need modular open systems approaches for data/model infrastructures
    viii. need modular open systems approaches for tool infrastructures
    ix. need to broadly develop a culture for continuous iterative development
    x. need digital information exchange standards for tech/program reviews
    xi. need visualization standards for tech/program reviews
    xii. need better training on model development, model governance, and model review
    xiii. need to realize more automation from the tools
    xiv. need automated evaluation and test strategies and tools for models and simulations

Share Lessons Learned

3. The DoD needs to organize and share lessons learned across all components. There are still relatively few defense system program offices that are implementing digital systems engineering and there appears to be little reuse of approaches from program to program, service to service at an enterprise level. Industry enterprise level approaches are more mature but still remain unique to program. The details of these implementations and lessons learned from them are not being widely shared.
    a. lack use cases for upstream and downstream use of data and models
        i. System program offices lack standardized approaches in practice for defining and using models and related data to specify and manage their developed and acquired systems
        ii. These would standardize on government reference architectures for both SE infrastructure and portfolios of systems – there is a lack of mature examples

iii. Models and data should be viewed as a risk management strategy – need a documented process and a program management focus
iv. The integration of mission/SoS models and system models is immature, program offices need SoS level views as stand-alone system models cannot reflect changes in context/use over time
v. System program offices lack documented examples of SE Mod as a quality improvement process
vi. There are not enough use cases and examples of SE Mod benefits

Stakeholder needs:

vii. need standard digitalized versions of engineering and acquisition processes and methods
viii. need reference approaches for data/model standardization and sharing
ix. need Program Manager guidance for using models as a risk mitigation strategy
x. need integration examples that span mission, enterprise and system architectures
xi. need examples of digital and model-based SE in Quality Assurance processes
xii. need more use cases showing the benefits of these transformations

b. Do not yet understand the benefits of and return on investment for SE Modernization

i. High cost of tools and adoption strategies are a barrier to entry for many program offices who are not given funding/schedule relief for this transformation
ii. Programs need revised cost estimation models that reflect efficiency of SE modernization components
iii. Programs need to have and to adopt measurement strategies and specifications for SE in general and modernized SE
iv. Programs need a means to value the multidisciplinary rigor and integration that comes with SE Mod
v. Programs need means to value the life cycle benefits and use of sustained digital artifacts
vi. Programs need examples of program realized efficiencies, and need long-term examples of the realized value of SE modernization

Stakeholder needs:

vii. need dedicated resources to support the implementation of new methods and tools
viii. need schedule consideration and program planning that includes methods development and training
ix. need revised/more complete cost estimation tools that reflect data collection and models
x. need standardized measurement strategies/approaches for DE and SE
xi. need examples of program realized efficiencies
xii. need means to quantify the value of the interdisciplinary rigor gained from DE

xiii. need means to quantify the value to operational evaluation from using DE processes
xiv. need means to quantify the value to production from using DE processes
xv. need means to quantify the value to sustainment from using DE processes

Ways and Means to Drive Adoption

4. The DoD needs ways and means to drive adoption into Program Offices and other related government functions. This is a large transformation effort and current guidance and policy does not easily translate to government and acquisition functions. Government activities such as mission engineering, requirements development, science and technology, technology development and prototyping, test and evaluation, and operations and maintenance must all contribute to development, use, and sharing of data and models. Acquisition activities such as budgeting, contracting, data rights and intellectual property, information security, planning, and others must adapt, particularly to the collaborative workflows inherent to digital system engineering, and make use of the engineering information digitally available which impacts their activities.
   a. Lack acquisition/engineering process integration
      i. There is not an effective terminology that integrates across different acquisition pathways and different areas of policy and guidance, causing confusing and lack of focus
      ii. Digital transformation is an enterprise level cultural change and the top-down/bottoms-up learning needed is just underway
      iii. Most programs involve legacy systems and these program offices are unable to/unwilling to integrate new SE practices into legacy systems improvements
      iv. Standard contract approaches and templates for defining & procuring artifacts in the digital ecosystem are not yet available
      v. Need program office consumable visualization standards for dashboards that aid management
      vi. There are not enough examples of acquisition artifacts available from early adopters

   Stakeholder needs:

      vii. need standardized terminology/ontology across all acquisition and engineering functions
      viii. need organizational change management/cultural change cases
      ix. need examples of legacy system adoption of DE and MBSE
      x. need standard contracting approaches and templates for collaborating around models
      xi. need more examples of acquisition artifacts resulting from data and models
      xii. need program office standard progress visualization approaches to model based acquisition

b. Policies do not incentivize programs to adopt new approaches
    i. Current guidance is stovepiped and inconsistent across acquisition pathways and engineering/management processes, maturing slowly
    ii. The DoD lacks an enterprise strategy to fund DE infrastructure
    iii. Some programs are early adopters, but digital transformation is not yet at the portfolio level
    iv. The DoD needs experienced individuals who can lead adoption of modernized SE practices, as well as breadth and depth of staffing to implement those practices
    v. Effective compliance measures are needed to measure adoption and build momentum for change

Stakeholder needs:

    vi. need enterprise-wide infrastructure funding approaches that improve affordability
    vii. need portfolio approaches and examples of data/model sharing across programs
    viii. need experienced adoption leaders to manage cultural change in program offices
    ix. need breadth and depth of staffing, and specialized training linked to roles
    x. need compliance measures & QA standards for shared data and models

These pain points are offered up as a list for further development. In next steps the government should take the initiative to agree upon and formalize each pain point (as was done with the Digital Engineering pain points) then develop plans and measurement approaches to track each item.

As part of this research, the pain points were used to inform our SE Modernization roadmaps. Each roadmap description in the next section lists the relevant pain points.

SE MODERNIZATION RESEARCH ROADMAPS

The culmination of the integration framework, pain points, and other research led to a set of digital SE modernization roadmaps to inform future developmental activities in this area. These roadmaps are not detailed in time, but generally represent a 5-year timeframe of activities to advance the SE Modernization initiative. The full roadmap is shown in Figure 16.

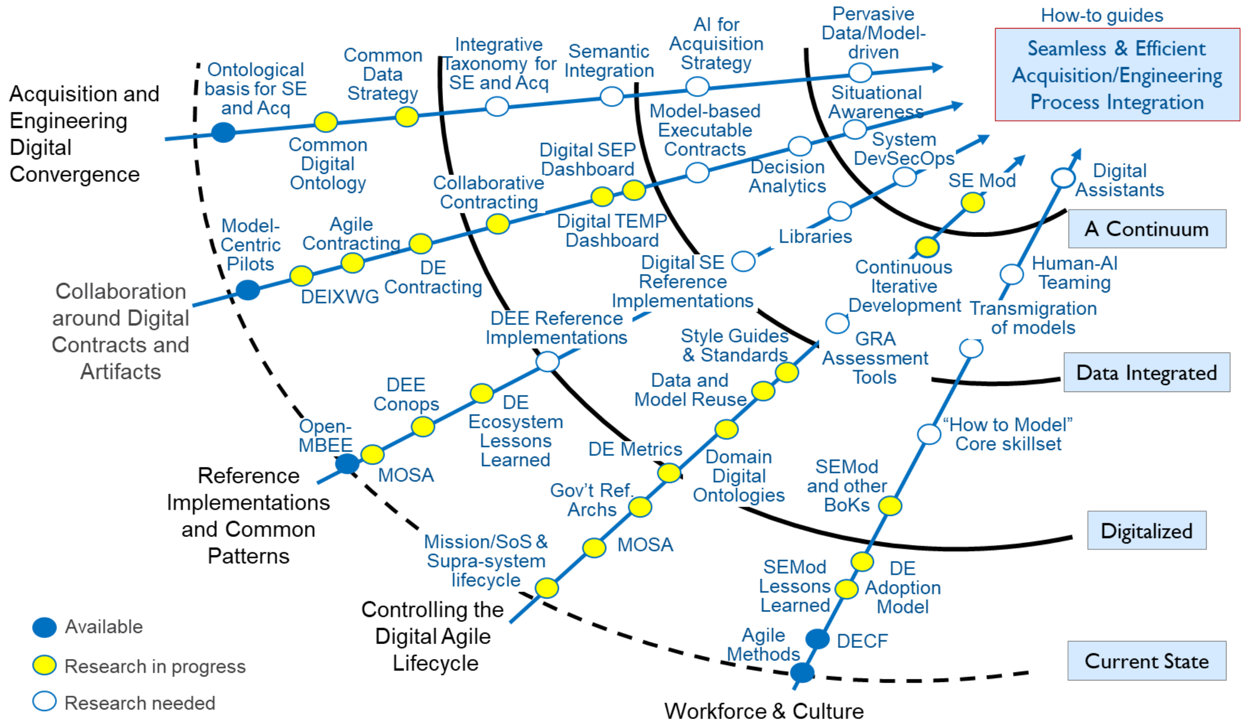


Figure 16. SE Modernization full roadmap.

The roadmap has a set of verticals (arrows) leading to a visionary outcome or set of outcomes, and each circle on these verticals represent a capability that is either currently existing (blue), in development now (yellow), or needs to be started (white). The color codes are our assessment of the current capability. The arcs in the diagram represent "capability frontiers" starting from the Current State, moving through a frontier where SE and Acquisition are fully Digitalized, then a frontier where and SE and Acquisition processes are fully Data-driven and integrated with underlying data artifacts, and finally to where SE and Acquisition look more like A Continuum of capability development and deployment activities instead of standalone programs with large time gaps. The convergence at the end of the vertical and frontiers is "Seamless and Efficient Acquisition/Engineering Process Integration" ideally represented in sets of policy issuances and related "How-to Guides" that aid program offices and other military acquisition/engineering functions in their transformation.

The following sections discuss each vertical in the roadmap with linkage to the SE Modernization pain points. Each vertical description includes the pain points, a bullet form description of each capability, and a discussion of next steps in terms of developmental activities.

Acquisition and Engineering Digital Convergence

Figure 17. Acquisition and Engineering Digital Convergense Roadmap.

This vertical responds in general to all of the pain points associated with the lack of seamless acquisition/engineering process integration, in particular the lack of an effective terminology that integrates across acquisition areas of change. In our research we found that the policy and guidance that links acquisition and engineering lacks clarity in language and there is no standard lexicon that defines this linkage across all of the pathways of the Adaptive Acquisition Framework (AAF). One can view the defense acquisition process in total as a command and control process, integrating across military needs and uses (doctrinal), acquisition practice, and engineering activities. There is currently no underlying ontology to drive data convergence, and no integrative taxonomy that spans military doctrine, acquisition, and engineering that can connect program data and methods.

The SE Modernization policy analysis found "*The common modernization driver in all of these (SE Mod) focus areas is 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. This does not mean everything must be connected (that is unlikely to ever happen) but that the process to move up and down the data transformation space is efficient and produces better quality. With this mental model of improved access and flow, a common integration framework can be pursued. Without it, stove-piping of people, processes and tools across lifecycle stages will continue to occur. The purpose of SE Modernization is thus to support more seamless and efficient digital integration of data and models across all program management, engineering, and acquisition process areas as well as deployment and use of military systems. We found this intent to be generally lacking in the current policy and guidance*."

In addition, the policy analysis found "*there is an inconsistent level of descriptive detail across documents by focus area that creates confusion. There is also varying sets of terminology and jargon used in different policies and guides that makes integration difficult*." As a result, the analysis recommended an ontology effort being conducted to identify the more specific recommendations for language consistency across policy areas. This led to the ontology research on the project described separately.

The driver for this roadmap is to enable more use of machine learning and other artificial intelligence technologies to integrate data across engineering and acquisition courses of action defined by missions and capabilities. In the long-term engineering and acquisition execution processes should become fully paperless and data/model-driven to massively reduce cycle times and increase program success. The common technical basis for this convergence is the use of semantic web technologies and their underlying digital ontologies, which must be developed for both the engineering and acquisition domains (there is not a published domain ontology for either). This drives our recommendation of a set of capability development activities noted in the following list:

- **Ontological basis for SE and Acquisition**: Upper-level ontologies such as Basic Formal Ontology (BFO) provide a formal structure to integrate ontologies. Mid-level ontologies such as Common Core Ontology (CCO) and Navy Strategic Systems Program (SSP) integrate taxonomies of generic classes and relations across all domains of interest and supports domain level ontology development. Research on this project demonstrated that acquisition and engineering domain ontologies can be created and linked to these existing published ontologies. This research provides a completed starting point.
- **Common Digital Ontology**: A suite of digital engineering and acquisition domain ontologies needs to be developed and published that facilitate convergence of acquisition and engineering groups, and integration of life cycle activities (acquisition vs. operation and service).
- **Common Data Strategy**: Strategies for data governance, data engineering, and data analytics need to be defined to drive business intelligence and analysis for decision making in DoD engineering, operations, acquisition, and program management. An ongoing AIRC project has defined a draft Innovative Data-Enabled Acquisition Strategy (IDEAS) framework that promotes "*the use of quality pervasive digital information, models, data, and analysis to empower cultural changes and innovation by improving acquisition workforce decisions, policies, functions, and processes to produce better and more timely outcomes and value for the warfighter*." This work is linking digital acquisition and digital engineering and should be continued.
- **Integrative Taxonomy for SE and Acquisition**: The ontology efforts with respect to SE Modernization will provide a digital foundation to resolve a common taxonomy across systems engineering guidelines, acquisition related guidelines, program management guidelines and operational doctrine. This is necessary to digitally integrate all sources of knowledge for engineering and acquisition domains consistent with military doctrine.
- **Semantic Integration**: This is needed to transform sources of knowledge into knowledge representations that can be further used for domain level inferencing, comparison, and gap analysis across DoD operational, acquisition, and engineering domains, and to use these sources to design Courses of Action (CoAs) for engineering and acquisition execution. CoA's are the core of military operational planning, and should become the core of acquisition strategy. For example, in the commercial domain AI-based CoA tools are now emerging in business planning activities such as customer relationship management, procurement management, and supply chain management.
- **AI for Acquisition Strategy**: In the longer-term machine learning and agent-based modeling approaches can be employed to produce and wargame predictive CoA strategies for agile acquisition. The DoD should explore research in this area.
- **Pervasive Data- and Model-driven**: In the fulfillment of this roadmap. engineering and acquisition execution processes should become fully paperless and data/model-driven to maximize efficiency and flow, massively reduce cycle times, and increase program success.

Defense acquisition and engineering today come together in a common framework under the DoD 5000 series policies and guides for material development and acquisition. However, the disciplines are not well integrated. Development of an underlying digital data imperative to link these disciplines together through common data analysis and visualization tools and digital course of action guides will provide a foundation for convergence. The combination of SERC and AIRC research is already working in this direction, and foundational research on ontologies and taxonomies, data strategies, and analytical tools should be continued. Research that recasts and links these activities using operational command and control should be explored.

COLLABORATION AROUND DIGITAL CONTRACTS

- **Pain Points**: Lack contract approaches/ templates, Lack revised examples of acquisition artifacts, Need PM consumable visualization standards

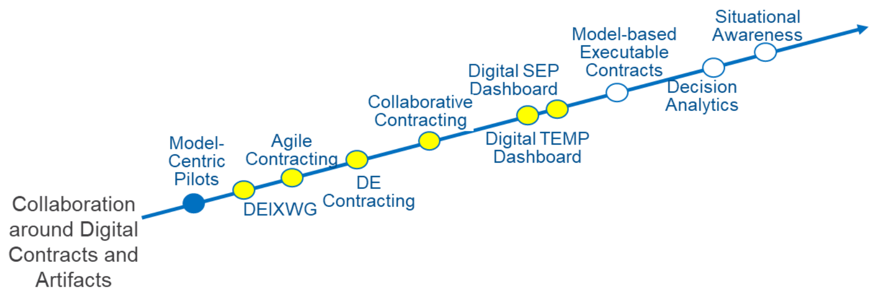


Figure 18. Collaboration Around Digital Contracts Roadmap.

This vertical also responds to all of the pain points associated with the lack of seamless acquisition/engineering process integration, in particular the lack of digital contract approaches/ templates, lack of revised examples of acquisition artifacts, and the need for better program manager consumable visualization standards. Responding to recommendations in the phase 1 research task WRT-1051 report, AIRC was separately funded to pursue research on Contracting for Digital Engineering. This effort is looking at DE contracting workflows and how government/government and government/contractor collaborate around models in program workflows. Digital model-based process that produce static document-based artifacts outside of the digital workflow create inefficiency and waste. Long-term SERC “Model-Centric Engineering” research with NAVAIR and Space Command addressed the question “can we do everything in the model” and integrated not just system modeling but also contracting, workflow, reviews, and approvals into the DE tool suite. Initial SERC/AIRC research efforts are envisioning conversion of Systems Engineering Plans (SEP) and Test and Evaluation Master Plans (TEMP) to digital artifact driven formats as these are the top-level SE required plans. (Refer to research tasks WRT-1043 and WRT-1071). These future tools should be considered as model-based interactive dashboards with near real-time program status, not digital static artifacts. In the longer term the DoD should strive for fully digital automated contracting, analytical tools, and program visualization capabilities that encourage collaboration around data and models.

The driver for this roadmap is to enable more use of machine learning, software orchestration platforms, advanced data analytics, and new visualization tools to gain full situational awareness across engineering and acquisition courses of action. In the long-term, engineering and acquisition execution processes should move away from static artifacts and highly aggregated milestones toward near-real time dashboards that apply advanced data analytics and continuous situational awareness of program operations. This also requires convergence around the use of semantic web technologies and digital ontologies, but this vertical is oriented around advancements in digital workflows and data analytics. This drives our recommendation of a set of capability development activities noted in the following list:

- **Model-Centric Pilots**: The SERC has completed several demonstration pilot programs exploring the art of the possible to achieve a representative set of SE and Acquisition combined activities 100% “in the model.” These so far have been oriented toward systems engineering technical processes but could be extended to additional acquisition activities as defined in a full contracting activity.
- **Digital Engineering Information Exchange Working Group (DEIXWG)**: This is a DoD sponsored community activity with INCOSE to develop a set of “common views” for executing digital, model-based engineering and technical reviews. This also demonstrates the art of the possible in the ability to standardize key program activities “in the models.” The DoD must continue to develop and promote these pilot activities, but must close the loop around lessons learned and implementation guidance to create more standardization across programs.
- **Agile, DE, and Collaborative Contracting**: There is a need for more flexible workflow-based contracting approaches for collaboration around data and models. Existing efforts to define and standardize contracting language are still following the current standards of static artifacts exchanged at major contract milestones, and only adding data and models to the static deliverables lists. Deliverables and contract points need to be driven by the flow of the engineering lifecycle, not the program lifecycle, although these should be linked. The DE Contracting research task will provide initial recommendations for these three areas, but further work will need to be done to develop and standardize DE contracting in line with agile workflows and collaborative processes.
- **SEP Dashboard**: All acquisition pathways and programs of any size should maintain and follow a Systems Engineering Plan (SEP) that defines and controls the engineering and management lifecycle activities. This remains an SE best practice independent of approval authority. This research envisions a digital version of the SEP that provides an interactive dashboard for a program office to plan, monitor, and control the program development process, built from modern data analytic and planning tools.
- **TEMP Dashboard**: All acquisition pathways and programs of any size should maintain a Test & Evaluation Master Plan (TEMP) that defines and controls the joint government/ contractor responsibilities and planning for test, verification, and validation. This research envisions a digital version of the TEMP that provides an interactive dashboard for a program office to plan, monitor, and control the systems integration, developmental test, and operational evaluation processes, built from modern data analytic and planning tools.
- **Model-Based Executable Contracts**: There is a need to bridge the gap between current legal language and digital data exchange using declarative (outcome-based)

transaction models, and software orchestration (dynamic workflows for multiple task automation). Model-based executable contracts are software programs that are stored and executed using blockchains to manage the transactions. Software orchestration automates the configuration and management of these programs. Outcome-based transaction models could move the completion of a static milestone and deliverable to a linkage between a performance milestone and evidence in a digital model (for example "100% design release" is satisfied when the product line management tool plan versus release metric reaches 100% as seen in the SEP dashboard). Commercial best practices to automate these contractable transaction points are evolving. Research in this area could better link engineering, program lifecycle, and technical management progress in automated, digital, machine learnable processes. Why is this important? Ideally, we could better plan and contract for the evolution of the system, not just the engineering and program management tasks.

- **Program Decision Analytic Tools**: Common digital ontologies and data strategies will enable development of new digital decision analysis tools using emerging artificial intelligence and visualization technologies to improve acquisition decision making. Linking deliverable progress to discrete tasks in an integrated master schedule to track actual system development progress is extremely inefficient. In modern software/DevOps environments all the software development and program metrics are integrated and tracked within a single tool suite. In other words management metrics are directed linked to the software code. Interdisciplinary digital systems models can ideally extend this concept to full program level tracking.
- **Program Situational Awareness**: The long-term goal is digitally connected visualization dashboards that achieve full near real time situational awareness and measures of performance across all engineering, technical, and management activities, even in extremely large projects.

REFERENCE IMPLEMENTATIONS AND COMMON PATTERNS

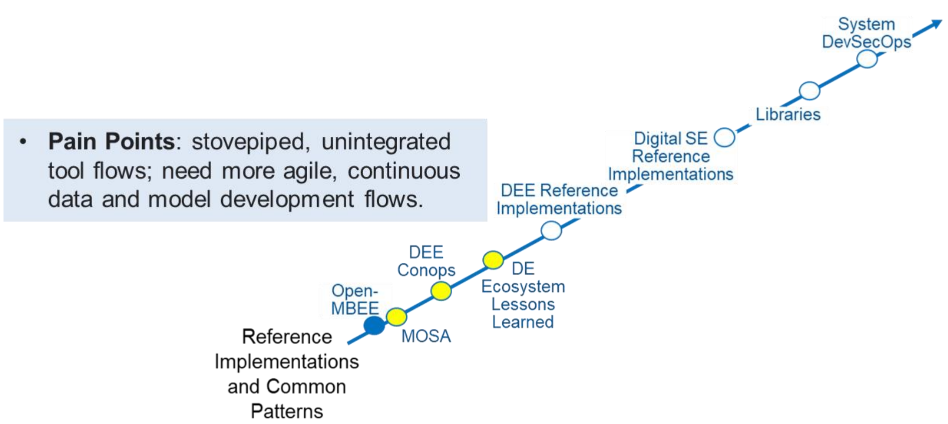


Figure 19. Reference Implementations and Common Patterns Roadmap.

This vertical responds in general to all of the pain points associated with current stovepiped and unintegrated tool flows and the need for more agile and continuous data and model development approaches. The Jet Propulsion Lab's Open-source Model-Based Engineering Environment (OpenMBEE) was the first toolset to support management of all data and all systems and disciplinary models in a systems modeling framework. The SERC Model-Centric Engineering research demonstrated that model management and visualization tools like Open-MBEE could be used to orchestrate both engineering and program workflows completely in the digital toolset. Today, the exemplar tool patterns used by most DoD programs that are supporting data and model-driven acquisition remain fragmented and non-standardized. This leads a program office to develop around the simplest tool infrastructures and defeats the core value of SE Modernization: seamless and efficient digital flows.

Modernized program offices need seamless and efficient digital engineering and acquisition ecosystems – information technology systems that support digital development workflows and products. While digital program management ecosystems can likely be standardized at the enterprise level, the digital engineering ecosystems will naturally vary by the types of systems being developed, produced, and maintained, and the disciplines needed in the process (a software only ecosystem will be simpler than a manufactured physical product ecosystem; a prototype might use a simpler ecosystem than a full weapon system lifecycle management ecosystem). This drives our recommendation of a set of capability development activities noted in the following list:

- **MOSA:** The government has mandated a modular open systems approach (MOSA) for its weapon systems. MOSA principles must also set the core business and technical approach for DE Ecosystem (DEE) architectures.
- **DE Ecosystem Conops:** As a next step, OUSD(R&E) should develop agreed upon concepts of operations and use cases for creating program/enterprise DE ecosystems and development of a joint federated model for procurement & assistance in development.
- **DE Ecosystem Lessons Learned:** The community needs an organized and categorized Body of Knowledge collecting lessons learned from government and industry on DE ecosystem patterns.; as well as an continual effort to translate lessons learned into action.
- **DE Reference Implementations:** As a further step, OUSD(R&E) should evaluate and promote community endorsed patterns and reference implementations for program/enterprise DE ecosystems based on differing system/SoS types. The DoD has done similar work in their software factory environments such as the Air Force Cloud One software hosting environment and toolset options. This can be structurally reused and extended to all engineering and management tools, but development still would need to address interoperable tool pipelines, not just tool hosting.
- **Digital SE Reference Implementations:** Longer-term we need community endorsed patterns for data/model development applications and associated procedural modeling techniques that determine how we model things. Systems modeling tools today all differ in the procedural methodologies they encode in their tools, as well as their underlying meta-models. Different enterprises are developing different modeling style guides, and these are incompatible. This may be primarily a

sharing of lessons learned and artifacts, but the DoD should encourage and perhaps host this sharing. In the longer term standardized training related to not just tools but also modeling methods is needed.

- **Libraries:** The tools and models should evolve over time where system lower levels of abstraction become standard libraries and designing a system model becomes more pattern-based. In the Software, Microelectronics Design, and Computer Aided Design communities library reuse has become normal. At the systems level much more research and development is needed.
- **System DevSecOps:** Ultimately this vertical should support a DevSecOps model for system capability deployment, where DE ecosystem and acquisition program management tooling supports continuous integration and deployment of warfighter capabilities from any program and any organization.

CONTROLLING THE DIGITAL AGILE LIFECYCLE

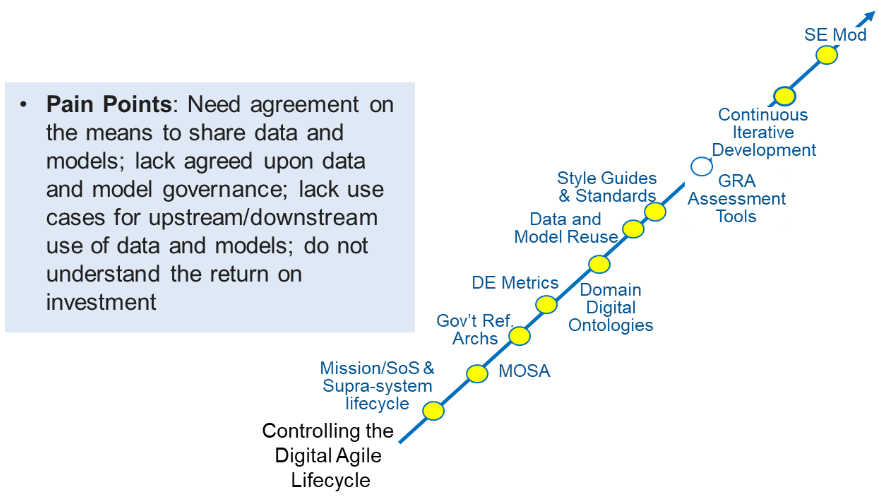


Figure 20. Controlling the Digital Agile Lifecycle Roadmap.

This vertical responds to many of the pain points in the build reference implementations, modernize SETR processes, and share lessons learned goals of SE Modernization. The government needs to develop or acquire and maintain the digital artifacts it needs to control the whole digital and agile lifecycles of its systems. This is the full supra-system lifecycle model that extends beyond any individual program or systems engineering lifecycle. We also list MOSA in this vertical because it provides the Title 10 acquisition authority for the government to retain and manage and make available all the long-term business and technical aspects of their mission, enterprise, and system architectures. A central concept of this vertical is architecture. Architectures are models and the evolution of digital systems engineering and architecting will provide greater fidelity of this control as the tools and methods evolve over time. Government reference architectures[4] (not just requirements) should become the acquisition baseline in each acquisition pathway, allowing the government more ability to manage adaptation and change as threats change and technology evolves.

This vertical is the core of SE Modernization. In the long-term, SE Modernization promotes more seamless and efficient system iteration through data and model reuse and continuous iterative deployment practices. This drives our recommendation of a set of capability development activities noted in the following list:

- **The Supra-System Model**: this thread begins with the re-envisioned acquisition/SE lifecycle model discussed separately in the research. The government needs to view SE as the integration framework for all technical and management lifecycles and processes, not just a material development. This includes mission architectures, system of system (SoS) architectures, and system architectures to the level that the government needs to control the full system "experience" across its lifecycle.
- **MOSA**: MOSA is the government's business and technical approach to manage adaptability and affordability of defense systems over time, managed at the portfolio and architecture level. It must not be viewed as just an interface control and intellectual property management tool, but as technical and management process to define and control government developed versus contracted aspects of a full system architecture over time. MOSA is a mechanism to control and manage an architecture, the focus should be on the methods, processes, tools, and skills associated with architectural design.
- **Government Reference Architectures**: GRA's are government developed, owned, and maintained authoritative sources of data and models that guide system design, development, production, and sustainment in an acquisition program. These exist at enterprise or portfolio levels. Figure 21 provides a good overview of the supra-system lifecycle activities associated with a GRA (Martin 2022). It should be noted that continuing to segregate policy and training under ME, MOSA, DE, and modeling and simulation functional areas bypasses the opportunity to grow system architecture functions, roles, and skills in the DoD. The DoD must invest in both the digital methods and related skills associated with reference architecture development.

[4] *Reference Architecture: an authoritative source of data and models that guides and constrains the instantiations of multiple architectures and solutions. The goal is to provide templates for solutions in a particular domain that stress commonality.
*Government Reference Architectures: guide system design, development, production, and sustainment in an acquisition program. A GRA should exist at the mission level and system of systems/family of systems level but can provide standardized approaches at any level of a system.

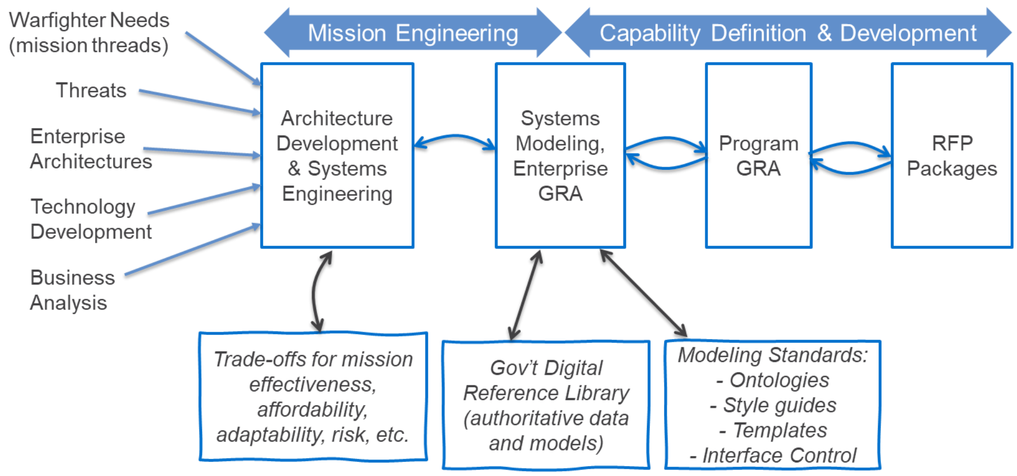


Figure 21. Government Reference Architecture in the Acquisition Process (adapted from Martin).

- **Digital Engineering Metrics**: Digital artifacts provide a more direct path to measuring and improving efficiency and quality of the defense systems development process to improve system deployment, cost, and schedule outcomes, as they allow us to directly measure the software artifacts that make up the digital thread and digital twins. Previous SERC research supported development and publication of the initial DE Measurement Framework (PSM 2022). Programs need to begin collecting data to inform longer-term enterprise measures and DE measurement metrics and reports need to become formal program office requirements. Also, efforts that continue to update this framework and collect lessons learned should be continued.
- **Domain Digital Ontologies**: A GRA will be expressed in a reference library which will become the digital graph of domain-specific models and relationships between entities in a mission, SoS, or system. With document-based systems engineering and acquisition exact language based relationships are not important, in digital modeling these domain level ontologies have become critical. Domain digital ontologies and their development will be necessary for constructing the data models that underly authoritative sources. Programs and portfolios must maintain these, and must train and employ people to manage them.
- **Data and Model Reuse**: A longer term outcome development of government maintained and provided libraries of mission/SoS/system data, models, and reference architecture templates will be reuse. Reuse will reduce program to program data ambiguity, improve learning, and increase overall speed of acquisition. Federations of reusable software models and other components is both a cultural change and a research program that needs its own well-funded set of programs.
- **Style Guides and Standards for Systems Models**: Systems modeling tools and the SysML language are relatively new compared to other software languages. There is a huge need to develop and share guides that produce consistency in system modeling methods and design as well as tools to improve interoperability and reuse across programs, portfolios and services. With SE Modernization community can wait for this to happen or we can put in place programs to encourage standardization.

- **GRA Assessment Tool**: What data is needed to say a GRA is acceptable, what are the criteria that the data and models need to meet? There are many standard reference models but little characterization of reference model standards. A specific research project should be conducted to advance the foundations, discipline, and practice of reference modeling.
- **Continuous Iterative Development**: CID is both an architecting and development process approach to manage risk by separately architecting platforms and capabilities and more frequently deploying and validating capabilities. It is now the core of software/DevOps approaches but very different from the traditional MDAP related DoD SE approaches. The DoD needs to continue to define, promote, develop, and support CID across both architecture and more continuous development processes.
- **Systems Engineering Modernization (SEMod)**: The outcome of this project in the long-term: evolution of SE lifecycle processes and digital tools to improve the efficiency and quality of defense systems development.

WORKFORCE AND CULTURE

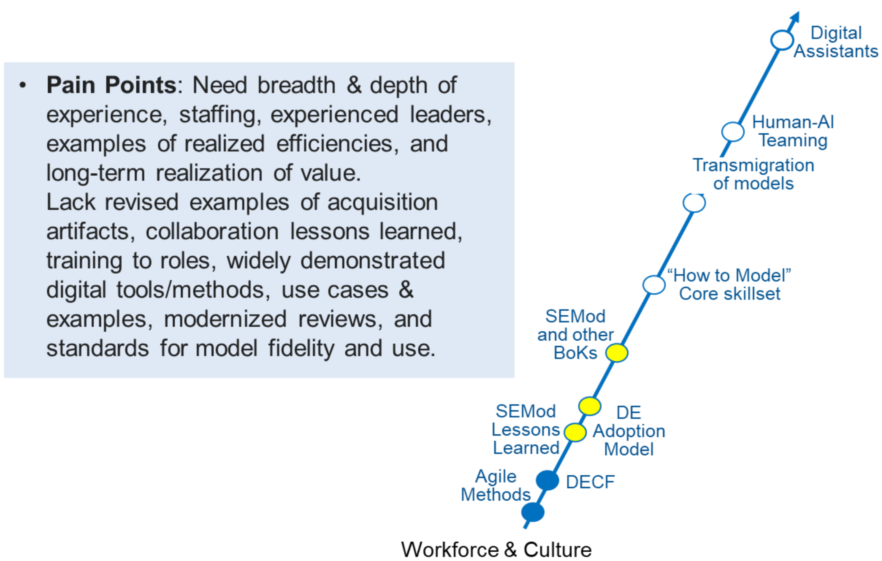


Figure 22. Workforce and Culture Roadmap.

Pain points related to workforce development and cultural adoption of modernized SE appeared in every "rib" of our pain points fishbone diagram. In this project we were teams with the DAU on their SE Modernization project, which consists of a set of training materials and topical webinars. Overall, these materials still largely separate content for each focus area, and need to be more integrative over time.

There are several unifying themes from the SE Modernization that need to drive workforce development activities in the future. These include moving all the software components of SE (data, models, software products) to established team and enterprise agile methods and tools, fully developing the digital competencies of an SE, and making the foundations of modeling and simulation essential skills of any government technical and management professional. In addition the capture of evolutionary lessons learned and a related body of knowledge as defined at the start of this initiative should continue. The final theme is automation, as efficiency will come from not just connectivity but from task automation. This drives our recommendation of a set of capability development activities noted in the following list:

- **Agile Methods**: DoD should promote integration and adoption of agile methods across all engineering and acquisition activities, not just software. There are enough published examples of agile transformation in hardware-intensive industries (Tesla, Saab) to build from, and many defense contractors have already made the transition. Any government processes that disrupt "flow" (in agile terms) should be retired or at most remain with rationale.
- **Digital Engineering Competency Framework (DECF)**: The SERC completed an extension of SE competencies into the digital engineering realm with the DECF. DAU is using the framework to guide their digital engineering courseware in development. Training by doing (within the DE tool ecosystem) is necessary to experience the benefits and create the culture. The SE community needs to address these competencies generally in all education and training to continue to grow the workforce.
- **Digital Engineering Adoption Model**: The SE Modernization project produced an initial framework to organize the benefits, enablers, and change management strategies and lessons learned for DE adoption. The DoD should develop a more quantitative approach to their digital and model-based systems engineering maturity assessments using this initial framework and adjust it over time. The DoD should further how-to guidance and sharing of lessons learned to programs on their adoption journeys.
- **SEMod Lessons Learned**: The SE Modernization project curated an initial set of key lessons learned from government and industry reflecting their digital transformation journeys across engineering, program and technical management, and acquisition, as well as a searchable framework for capturing these. Continued sharing of lessons learned is critical to government/contractor SE modernization.
- **SEModBOK**: This project prototyped a body of knowledge with the goal to reflect the integration of both fundamental knowledge and how-to guidance for doing modernized digital engineering and acquisition practice. The prototype SEModBOK contained only high level guidance, based on this research we now have additional artifacts and lessons learned. This reference library will continue to be useful as the initiative proceeds.
- **"How to Model" Core Skillset**: An aspirational goal in this roadmap is that everyone in acquisition and engineering gains core skillsets to represent data and solve problems in digital models. In the adoption research we identified three separate roles each of need training in modeling fundamentals and practice: reviewers (all who need to know how to use models to make decisions); developers (people building and maintaining the models); and architects (senior engineers assisting with the content of the models). The foundational concepts underlying development and use of models are well understood and can be trained to anyone. The DoD should provide the focus on this training area. Additionally, material should

be prepared and used to help leadership and decision makers transition from a pre-AAF method of acquisition, to a digitalized method, with automation. Help the leadership be comfortable with the change.

- **Transmigration of models** (transmigration: from one state of existence to another): This is an appropriate term to define a state where the people in any one acquisition role are comfortable using models from any other role (to some level of abstraction). This implies both advances in educational methods that train "how to model" and in modeling tools that can adjust views between abstraction levels based on reviewer needs. Three specific needs from the pain points analysis are visualization standards for tech/program reviews, tool suites that provide means to view/extract data at different levels, and model fidelity and modeling style guidance for different use cases.
- **Human-AI Teaming**: The companion SERC roadmap on AI and Autonomy identifies a number of detailed research and technical areas for future SE linked to Human-AI Teaming and Digital Cognitive Assistants for augmenting engineering and acquisition tasks that include information intensive activities or have inefficient workflows. Workforce development in this area should also concentrate on design of appropriate tasking and human-computer interface strategies for digital assistants in partnership with humans. The output of research in this area would be **Digital Cognitive Assistants**: AI assistants that help to identify areas to focus on, data analysis results, etc. SE Modernization workforce programs should not be just training humans, but also analyzing opportunities to improve workforce productivity, create communication improvements, redefine training needs, etc. to take advantage of the digital transformation.

RECOMMENDATIONS

At the convergence of the roadmaps is "How-to Guides for Seamless and Efficient Acquisition/Engineering Process Integration." The DoD must create a more agile and responsive acquisition system. To achieve this it must move with the rest of the business world to digitally transform itself and eliminate unnecessary and wasteful manual tasks. The challenge for the Office of the Undersecretary of Defense is to lead this transformation – the transformation will not succeed if every service and program office is left to independently undergo its own transformation.

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