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Agile Development of Hardware-Reliant Systems

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Abstract

The Acquisition Innovation Research Center (AIRC) and Software Engineering Institute (SEI) sponsored a workshop on Agile Development of Hardware-Intensive Systems. This paper summarizes the results from that workshop and further discusses concepts of agile and DevSecOps in defense acquisition programs that include hardware-intensive development activities. Every technological revolution triggers changes in how work is done and managed, as well as how people are managed. As a result, traditional approaches become insufficient for addressing new problems. Commercial industry has adopted agile practices in software, hardware/software systems, and services to address rapidly changing threats to and opportunities in their business. The Department of Defense (DoD) now faces similar external drivers and must move to agile practices across all acquisition processes and functions. Workshop speakers and participants identified 10 primary themes that should scope transformation of future defense acquisition for all types of systems, not just software.

Research Issue

Rapidly advancing threats and technologies have increased the need for the U.S. Department of Defense (DoD) to develop, field, and upgrade operational capabilities to ensure mission effectiveness and success more quickly. Agile development along with DevSecOps (development, security, and operations) can accelerate acquisition and improve relevance. Industry has successfully applied agile and DevSecOps to software, hardware, and inter-reliant hardware/software systems. The DoD has embarked on this journey—but primarily only for software systems. However, continuous innovation and deployment are a total system concern and involve hardware components in a system as well as software, business process, funding, and all other human-oriented intangible components.

Agile enterprises recognize that deploying new systems or capabilities cannot wait on the slowest components of the system. Instead, all components need to be deployed when ready, and both systems and organizations need to be structured to support modularity and flow. All organizational processes that might delay these components must also make the shift, including program management, contracting, test & evaluation, sustainment & logistics, and financial management.

The DoD has struggled to make the shift to agile. Over years of employing more sequential approaches, the Department, like other organizations, has created siloed organizations responsible for one part of the process with movement to a different stage (silo) triggered by full completion of the activity, coupled with large testing events at the end of development. Alternatively, the core principle behind agile is “flow.” The flow of work should continue consistently across cycles of product strategy, resources, product development and test, and product support. With digital transformation, the DoD can reduce phase durations and cycle times in all phases of development and acquisition. By integrating agile and DevSecOps initiatives with Digital Engineering, the DoD can improve flow, allowing components to react more quickly to changing end-user demands. Agile practices for hardware-intensive systems in Digital Engineering and Digital Acquisition are a primary driver to agile product development, along with focused adaptations in acquisition practices and policy in support of agile transformation.

Research Results

The Acquisition Innovation Research Center (AIRC; 2023) and Software Engineering Institute (SEI) convened a workshop on April 18–19, 2023, focused on Agile Development of Hardware-Reliant Systems. The workshop was co-sponsored by the Office of the Under Secretary of Defense for Acquisition and Sustainment and the Office of the Under Secretary of Defense for Research and Engineering. Forty-eight experts, including 17 speakers from government, industry, and academia, gathered together for a working discussion and sharing of best practices, lessons learned, challenges, and progress. The stated goal was to develop a set of foundational practices and research vectors relating to hardware-related agile, DevSecOps, and Digital Engineering/Acquisition to provide practical advice to programs in applying these techniques to both hardware and software elements of acquired systems while facilitating workforce training and improvement.

Commercial industry has adopted agile practices in software, hardware/software systems, and services to address rapidly changing threats to and opportunities in their business. The DoD now faces similar external drivers and must move to agile practices across all acquisition processes and functions (Vesonder & Hutchison, 2022). Workshop speakers and participants identified 10 organizational goals that should scope transformation of future defense acquisition for all types of systems, not just software. Organizations and programs undergoing digital transformation of their acquisition and engineering processes should work to adopt these goals to drive their transformations.

1. **Shift Learning to the Left**. This should be added as the 13th principle to the 12 Agile Principles (Manifesto for Agile Development, n.d.). In hardware-reliant systems, agile practices augmented by digital models, prototypes, and test infrastructures help bring learning forward, reduce integration risks, and create more flexibility in long-term design decision points. The workshop highlighted the value of knowledge and learning in the development process. Results emphasized the need to capture and share knowledge, as well as the importance of gaining insights and feedback at various stages to improve the final product. Digital models are the primary knowledge sharing tools, and organizations must manage data and models as a means to truly experiment and prototype in the digital realm to accelerate learning as far left as possible.

2. **Design for Change**. Intentionality in the early design stage of hardware-reliant systems to accommodate innovation in later stages of product development is an enabler of agility. Related concepts are design for iteration and flexibility. Too often in the DoD, designing to maximize performance and satisfaction of performance requirements results in systems that are inflexible to iteration and change. Choosing the elements of the system to emphasize in this strategy helps anticipate evolution of components that have the most potential for change late in cycle or those for which innovative change will have the most pronounced performance gain. Modularity must be a primary design driver. The concept of flexibility in design along with digital models promotes a strategy of “don’t decide until you have to” lock in hardware design components.

3. **Design for Flow**. The current inefficiency of the Defense Acquisition System (DAS) could be improved by broad adoption of a few underlying premises of agile: create direct collaboration between users and developers, encourage simplicity, and create continuous flow of value. This is a DoD enterprise-level shift independent of hardware or software acquisition. Agile is fundamentally an approach that seeks to improve process flow. Currently in the DAS, the flow from warfighter need to capability acquisition passes through many organizations and processes before it becomes an acquisition program (of any type). This changes interpretation of needs and requirements, isolates the real customer from the capability development and interrupts the flow of work from need to capability. A further barrier to flow is the transactional nature of DoD acquisition, which can disrupt consistency and interrupt flow. Modular acquisition

practices help here but are rarely used. The workshop highlighted the importance of directly aligning ambitions and efforts of the users and developers with the actual capabilities required in the system, which in agile principles is called encouraging simplicity. Connecting Combatant Commands and their priorities directly to the acquisition process is one strategy noted at the workshop. The DoD requirements process often runs counter to this, preferring to aggregate needs and requirements into larger acquisition efforts. Design for flow requires that every function in the DAS and the primary contractor processes be aligned to maximize flow rates from warfighter need to capability delivery.

4. **Overcome the Single Batch Mindset**. The historical Acquisition Category (ACAT) I acquisition process remains ingrained in a waterfall mentality, even though alternative pathways are available. The workshop addressed the challenges of the single batch mindset and the belief that everything must be understood before implementation. Instead, one is encouraged to find ways to overcome these barriers and adopt a more flexible and adaptive approach. This implies an enterprise-level shift to allow more frequent delivery of working systems (or system elements) through reconciliation of development and delivery cycles for best effect. Rather than compounding the effect of slower cycles that drive the pace of system-level delivery, a refactoring of the contributing streams of work can assure flow enabled by smaller batches of work. Milestone completion remains important but must be translated into buying down risk, not just criteria completion. Integrating both a consistent work cadence and milestone-driven goals are critical to agile in hardware-intensive systems. A warning: The fact that the Software Acquisition (SWA) Pathway specifically waives ACAT I designation even for large software programs is a signal that the historical DAS has a single batch mindset to overcome. There is a danger that agencies using Middle-Tier Acquisition (MTA) and Software pathways may just bypass onerous ACAT I milestone approval processes and damage the flexibility granted with these other pathways. The concept of “tailoring-in” instead of “tailoring-out” regulatory acquisition requirements based on need was discussed. A better approach is to make all pathways more efficient using agile principles.

5. **Decomposition and Partitioning**. The workshop noted the concept of decomposing capabilities and finding clever ways to partition them. Breaking down complex systems into smaller, manageable components allows for faster learning and better understanding of individual elements. Agile practice takes advantage of modularity to architect systems that can be evolved over time. Control of interfaces and application program interfaces (APIs) is fundamental to both defining the work in the system and the team skills needed to do the work. Modular Open Systems Architecture (MOSA) precede agile development in both software and hardware systems, as well as the infrastructure used to develop them.

6. **Deliver Working Software Frequently**. The Agile Manifesto focuses on delivery of working software as the primary measure of progress. All systems including hardware-intensive systems today are software intensive, so programs should continually deploy and redeploy working software into everything they do. Meaningful movement of prototypes from virtual environments to physical realizations to operational use has tangible benefits when the software is reused from one product to another. Programs should embed deployable software into simulation and training systems, allowing all developers and users to experience the operational use of the product.

Figure 1 depicts this concept.

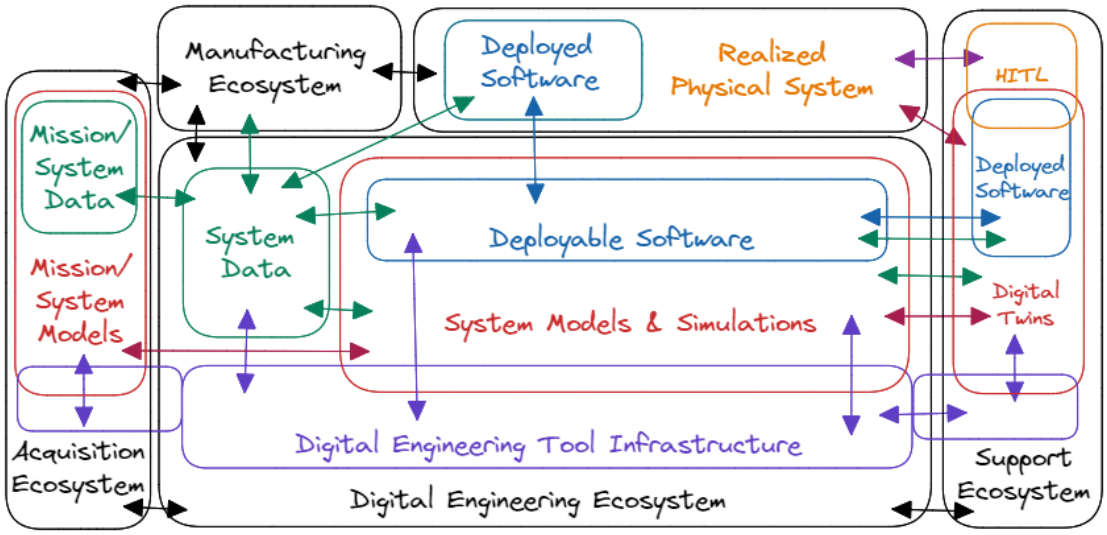

Figure 1. Today's Systems Should Plan for Deploying Working Software Frequently Into All Aspects of Program Planning and Development

7. **Hardware-Intensive Agile Requires Front-End Investment**. In his paper "Managing the Development of Large Software Systems," Win Royce (1987) introduced the waterfall model and noted its fundamental flaw: Testing is at the end; therefore, flaws in the design are not identified until the end. Agile in hardware-intensive systems requires front-end investment in test activities and infrastructure to buy down end-item risk. For example, SpaceX's™ investment in and experience of learning from multiple launch failures is an example of the culture and mindset required for innovation and continuous improvement. The workshop highlighted the value of automating as much as possible while also being mindful of the cost and benefits of automation. Investment in model-based engineering tools, multiple systems-level prototypes, and hardware-in-the-loop environments will be critical for "shifting left" to successful agile implementation in hardware-intensive systems. However, return on investment (ROI) is not easily quantifiable up front.

8. **Configuration Management and Branching Strategy**. The concept of branching – independent lines of work that stem from a central design – is a practice in both software systems and models. Intentionally integrating branching strategies into simulations, test articles, certification articles, and manufacturing systems is a necessary strategy in hardware-intensive systems. However, branching can lead to configuration management failures and must be implemented appropriately. This is a practice that needs more exploration and lessons learned.

9. **Managing the Digital Infrastructure**. Organizations need to have dedicated persons or groups to manage integration of their digital tool infrastructures. This is more difficult in hardware-intensive programs because the tools are more diverse and less well-integrated than in today's software/DevOps environments. Modern tool infrastructures for hardware-intensive systems may also integrate manufacturing systems, 3D printers, robotics, and associated digital engineering tools. Employing a dedicated data analytics team to monitor tool effectiveness and improvements is necessary.

10. **Continuous Focus on the Workforce**. There is a need to continuously train the entire workforce on agile principles. Much of the DoD organic workforce is familiar with milestone-driven development practices but needs continuous indoctrination into agile methods. The workshop acknowledged the importance of structuring and organizing responsibilities into roles different than those in traditional development. The workshop emphasized the

interconnectedness of individuals, knowledge, and the system being developed, and the need to assemble expertise in specific roles. The value of agile training, independent of selected methodology, is the mindset shift to new roles and ways of doing business.

In summary, these 10 goals can form a checklist for organizations to plan and measure their organizational agile transformation. In DoD acquisition, the government and lead contractor should jointly evaluate these goals. In checklist form, these are:

( ) We have integrated digital modeling and simulation with our selected agile methodologies and deployed a test infrastructure to shift learning to the left.

( ) We have specified and organized our system architectures for iteration and flexibility as Key Performance Parameters and trained our design teams to consider these qualities at every level of design.

( ) We have redesigned all of our organizational processes necessary to deliver capabilities to remove all waste and delay and maximize flow of value to the end user (warfighter).

( ) We have redesigned our technical review and certification processes to emphasize flow over batch size and are integrating smaller in-process reviews with larger system/capability reviews to balance capability delivery with appropriate certifications.

( ) We have systems engineering processes that embrace modular open systems approaches and work decomposition strategies that emphasize small teams and faster learning, as appropriate to the system.

( ) We have created a “software first” mentality in our organizations and are developing and testing critical software capabilities at every stage of design in every deliverable product.

( ) We have invested in the digital infrastructure, high-fidelity modeling and simulation tools, and test automation strategies necessary to move testing to the front-end of every component development flow.

( ) We have mature digital configuration management approaches allowing design teams to iterate at their level and merge design iterations into the full system design.

( ) We manage the digital infrastructure and associated processes and tools as integral to system and product design and employ the necessary data management and analytics teams to maintain flow across our digital tools as well as extract progress.

( ) We have deployed appropriate training and incentives to shift the mindset of everyone in the organization from “single batch” to “continuous flow.”

The leading conclusion reached by the participants was that the agile development of hardware-reliant systems is not only possible but is being done today! A number of commercial hardware-intensive product development companies today are “born digital and agile” and are paving the way with lessons learned. It will be more difficult for the DoD and defense industrial base to “become digital and agile,” but this must be a goal of the whole DAS. Agile development of hardware-reliant systems requires a different mindset. Elaborating requirements in periodic demonstrations of new capabilities, with a notable tolerance of early learning failures, is needed. Learning appropriately from short, iterative development cycles that focus on testing with frequent user feedback, can deliver a core set of essential capabilities to warfighters with the rest of the system elements following the initial minimum viable system versions. This does not mean that a critical test and certification of a new hardware element should be shortchanged,

just that the flow of all other components should be organized to continue in digital simulations and prototypes and merge into that test and certification process at the appropriate time.

Fundamentally, the approach “shift learning to the left,” which could be considered a new principle for the agile manifesto, was considered essential for a hardware agile manifesto. Finally, decreasing the “acquisition distance” between the warfighter (combatant commands) and this type of capability acquisition would be an essential enabler towards a more agile practice for hardware-reliant systems.

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