Agile Development of Hardware-Reliant Systems

Research Workshop, April 18-19, 2023

Sponsored and organized by the Office of the Under Secretary of Defense for Acquisition and Sustainment, Office of the Under Secretary of Defense for Research and Engineering, the Acquisition Innovation Research Center, and the Carnegie Mellon University Software Engineering Institute.

ACQUISITION INNOVATION

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Executive Summary

Background and Purpose: The Acquisition Innovation Research Center (AIRC) and the Software Engineering Institute (SEI) at Carnegie Mellon University (CMU) hosted the *Agile Development of Hardware-Reliant Systems Workshop* on 18–19 April 2023. The interactive workshop was comprised of practitioners in agile development methods and acquisition from across industry, academia, and the Department of Defense (from the Office of the Secretary of Defense and Combatant Commands). The workshop:

- Disseminated AIRC study findings and collected further lessons and insights from industry and Department of Defense (DoD) best practices.
    - o The AIRC study of Agile development beyond software was requested by the Joint Explanatory Statement of the Committee of Conference that accompanied the FY 2021 NDAA (House of Representatives, 2020, pp. 1761–1762).
- Invited Keynotes from U.S. Indo-Pacific Command (USINDOPACOM) and U.S. Special Operations Command (SOCOM) on capability deployment needs and practices.
- Invited technical briefings from industry, academia, and DoD that covered agile acquisition issues, lessons, and best practices involving development, systems engineering, and management of hardware/software systems acquisition.
- Facilitated discussion sessions on different perspectives of agile development in systems and key enablers of agile practices in DoD acquisition.

Key Workshop Takeaways:

- Agile development of hardware-reliant systems is possible and is being done today!
- Faster delivery of the most critical capabilities to the warfighters can be achieved through a different mindset, agile requirements (capability statements), tolerance of early learning and failures, and short, iterative development and testing with user feedback.
- Decreasing the distance between the warfighter (combatant commands) and capability acquisition is an enabler toward more agile practice.

Workshop Summary

The Challenge: 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 development, security, and operations (DevSecOps) 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, primarily only for software systems. However, continuous innovation and deployment is a total system concern and involves hardware components in a system as well as software, business process, funding, and all other human-oriented intangible components.

Workshop Background: 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. 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, each responsible for one part of the process with movement to a different stage (silo) triggered by full completion of the activity, coupled with large capstone testing events at the end of development. Alternatively, the core principle behind Agile is “flow,” i.e., 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, the DoD can improve flow, allowing components to react more quickly to changing end-user demands.

Workshop Goals: Develop a set of foundational practices and research vectors relating to hardware-related Agile and 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.

Primary Insights: As noted by workshop speaker Harry Koehnemann, 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 DoD now faces similar external drivers and must move to agile practices across all acquisition processes and functions. Workshop speakers and participants identified a number of themes that should scope transformation of future defense acquisition for all types of systems, not just software. These themes are summarized here:

Shift Learning to the Left. This should be added as the 13th principle to the 12 Agile Principles. 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 speakers highlighted the value of knowledge and learning in the development process. Almost all 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.

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. 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. The strategy of "don't decide until you have to" is one that was seen in some notable workshop examples. They discouraged pursuing new technologies or tools solely for the sake of novelty and urged focusing on meeting the specific needs of the system.

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 speakers emphasized the importance of 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. The DoD requirements process often runs counter to this.

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 speakers addressed the challenges of the single batch mindset and the belief that everything must be understood before implementation. Instead, it 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. Speakers noted that 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.*

Decomposition and Partitioning. The speakers discussed 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.

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.

Hardware-Intensive Agile Requires Front-end Investment. In his paper "Managing the Development of Large Systems," Win Royce 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. One speaker noted SpaceX's™ investment in and experience of learning from multiple launch failures as an example of the culture and mindset required for innovation and continuous improvement. Another noted the value of automating as much as possible, while also being mindful of the cost and benefits of automation. Multiple speakers noted that 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, participants noted that return on investment (ROI) is not easily quantifiable up front.

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. Several speakers mentioned that intentionally integrating branching strategies into simulations, test articles, certification articles, and manufacturing systems is a necessary strategy in hardware-intensive systems. This is a practice that needs more exploration and lessons learned.

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. One speaker mentioned employing a dedicated data analytics team to monitor tool effectiveness and improvements.

Continuous Focus on the Workforce. Speakers familiar with DoD program offices noted 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 speakers acknowledged the importance of structuring and organizing responsibilities into roles different than those in traditional development. They emphasized the interconnectedness of individuals, knowledge, and the system being developed, and the need to assemble expertise in specific roles. The speakers cautioned against overapplying certain methodologies or technologies. The value of agile training, independent of selected methodology, is the mindset shift to new roles and ways of doing business.

Speaker Summaries

Summaries from Day One (April 18, 2023)

Welcome, *Mr. David Cadman, Senior Executive Service (SES),* *Director for Acquisition Data and Analytics, Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S))*

Mr. Cadman stated that when it comes to invoking faster-paced solutions, we need something akin to spiral development mixed with agile requirements development, mixed with overarching speed to address emerging concerns. This is especially true since adversaries can simply exploit small, single points of failure in the Department to be successful. In addition, hardware is rarely at the forefront of the agile discussion. Middle-tier acquisition (MTA) was a congressional act that allowed rapidly developed fieldable prototypes within an acquisition program, but it is not the end solution.

Keynote Speaker, *Mr. Jim Smith,* *U.S. Special Operations Command (SOCOM)*

Mr. Smith emphasized agile acquisition approaches for effective solutions. SOCOM's smaller scale and streamlined decision-making allow for agile and rapid response capabilities. Through collaboration and integration with the Defense Acquisition System (DAS), Agile Requirements Process, and Technology-Based Solutions, SOCOM ensures efficient decision-making and coordinated processes. In middle-tier and software acquisition, SOCOM adopts tailored requirements processes and deviates from traditional methods to enhance agility and meet unique operational needs. This approach, combined with hardware prototyping and down-selection processes, reduces risks and enables the transition to firm-fixed-price contracting for final development and integration.

During the Q&A session, Mr. Smith stated, "It is not about accepting risks, but rather it is a risk mitigation strategy that involves the entire community and understands the bigger picture. It is not just about achieving objectives; it is about comprehending the overall game." He emphasized that there is a need for oversight, and it should be embraced whenever possible, but imposing risks on the operational force or limiting commanders' authority in the acquisition space is worrisome.

Featured Talk: Research & Engineering (R&E) Software Strategy, *Mr. Allan Dianic,* *Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E))*

Mr. Dianic discussed the strategic approach for systems modernization. The strategy aims to address the DoD's lag in software compared to hardware considerations by identifying a path forward and fostering advancements in software technology over the next 10 years. This strategy emphasizes collaboration with services, explores successful commercial software practices, and focuses on four pillars: shifting left, modern ecosystems, workforce development, and acquisition evolution. Challenges include security, complexity, managing software and hardware complexity, and integrating software bill of materials requirements. By leveraging digital engineering, collaboration, and innovative solutions, the DoD aims to achieve effective software and systems modernization to meet evolving needs.

Featured Talk and Q&A: Agile Across a Large DoD HW/SW Program, *Ms. Brigid O'Hearn,* *SEI, Carnegie Mellon University*

Ms. O'Hearn spoke on agile adoption and overcoming challenges, starting with experiences on the F-35 program. The program successfully adopted agile practices to deliver capabilities more rapidly. Key factors included identifying minimum viable processes, fostering collaboration, prioritizing user engagement, and embracing incremental delivery of capabilities. The program emphasized hands-on experience, cross-functional collaboration, and organizational

alignment to ensure effective development. Overcoming challenges involved shifting governance strategies, establishing lead systems integrators, implementing a modular open systems approach, and investing in hardware-in-the-loop labs and testing facilities. These efforts showcased the value of agile methodologies and the importance of addressing hardware-in-the-loop labs in an agile environment.

Featured Talk: Agile in HW-Reliant Systems, *Ms. Robin Yeman,* *Consultant*

Ms. Yeman discussed the application of Agile principles to hardware development, highlighting key considerations such as incremental prototyping, shorter iteration cycles, cross-functional collaboration, and security and compliance. Several successful examples of Agile methodologies in hardware development were cited. Lean agile principles and practices have emerged as a method for companies to become more agile and adapt to change in the digital age. Embracing lean agile methods requires a different mindset, focusing on value, cross-functional teams, and continuous development and evolution. Planning is done in multiple horizons, large batch milestones are replaced with smaller, more frequent learning milestones, and leaders play a crucial role in supporting learning.

Featured Talk and Q&A: SAFe Methodology in HW-Reliant Systems, *Dr. Harry Koehnemann,* *Scaled Agile, Inc.*

Dr. Koehnemann discussed the adoption of agile practices in hardware-focused industries like automotive and the shift in attitude towards agile methodologies. The automotive industry is experiencing significant investments and challenges, with some brands potentially not surviving the next five years. Lean agile methodologies, such as continuous learning and value-driven approaches, help reduce uncertainty and embrace market changes. Agile hardware development requires organizing around value, scaling practices for larger systems, specifying the system incrementally, and utilizing multiple planning horizons. Examples from companies like General Motors and Tesla demonstrate the success of agile principles in hardware development and manufacturing.

Keynote and Q&A: MBSE Mis-use Cases, *Mr. Will Hayes,* *SEI, Carnegie Mellon University*

Mr. Hayes leads SEI's Agile Transformation Team, which conducts research to redefine Agile in challenging environments, considering specific contexts and exploring Agile beyond its application to software development teams. Mr. Hayes shared five stories that highlight patterns of implementation for Model Based Systems Engineering (MBSE) in DoD programs and organizations. These stories provide use cases for this enabler of agile development, in which the full value of MBSE may not yet be realized. Many of the stories are anchored in the classic challenges of technology transition. The obstacles presented have a common basis in the need to change mental models and apply "shift-left" approaches to complex engineering work. Government engineers engaged in early lifecycle activities enable agility in new ways – especially for hardware-reliant systems.

Summaries from Day Two (April 19, 2023)

Welcome, *Mr. Tom Simms,* *Acting Principal Deputy Director, Systems Engineering and Architecture (SE&A), Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E))*

Mr. Simms mentioned that this workshop aims to enhance the engineering process, promote shared understanding, and accelerate technology delivery to the warfighter. Agile methodologies, including early user engagement, iterative feedback, risk mitigation, and adaptation, were emphasized as effective approaches for meeting evolving requirements and addressing emerging threats. However, the transition to agile practices requires addressing cultural changes, tool and environment requirements, and workforce training. Mr. Simms also noted the workshop's focus on establishing foundational practices and research directions in hardware-related agile, DevSecOps, digital engineering, and digital acquisition.

Keynote and Q&A: Industry Perspective, *Dr. Jeff Boleng,* *Joby Aviation*

Joby Aviation incorporates agile practices in both software and hardware development, leveraging talented engineers with diverse expertise. Their philosophy emphasizes instrumenting everything possible to gather invaluable data. Joby's goal is to manufacture thousands of aircraft per year, which poses unique challenges as no other aircraft has been produced at such a scale. Agile engineering is at the core of their operations, guided by agile and lean manufacturing principles and essential ingredients such as CNC machines, 3D printers, and reliable digital engineering tools. Automation, collaboration, and certification alignment with authorities like the FAA are key focus areas for Joby. They recognize the importance of comprehensive testing, traceability, and continual improvement in ensuring safety and quality. The 737 Max incident serves as a reminder of the need for thorough evaluations despite rigorous certification processes.

Featured Talk: Agile Methods in DoD Acquisition, *Mr. Sean Brady,* *Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S))*

The software pathway enables departmental reforms in certification, cost estimation, and interoperability testing, aiming to deliver software into production within a year. Ongoing education and implementation efforts are essential for successful transformation. Leveraging existing infrastructure facilitates streamlined processes for hardware-reliant systems. Collaboration between government and industry software teams, along with automation, plays a vital role in achieving operational efficiency. This approach emphasizes flexibility, speed, and the use of five key artifacts during the planning phase to ensure a streamlined process and assess value for decision-making.

Featured Talk and Q&A: The Agile Program Office, *Dr. Michael Orosz,* *Information Science Institute, University of Southern California*

Dr. Orosz addressed the challenges of software and hardware integration in a program office's acquisition environment. Workforce training, particularly in DevSecOps, is crucial, along with recommendations for upfront systems engineering, early near-operational environment establishment, advance story allocation to sprints, and addressing Earned Value Management Systems (EVMS) challenges. The organization operates in a systems of systems environment, aiming to transition the workforce into agile methodologies, managing capabilities in the backlog and Program Intervals (PIs). Programmatic issues arise when tools are introduced into secure environments, necessitating continuous training due to high turnover rates. Early near-operational environments, robust systems engineering, and manual testing involvement are prioritized, with a focus on optimizing non-automated testing strategies.

Featured Talk and Q&A: Engineering in an Agile Culture, *Dr. Suzette Johnson,* *NDIA Agile Delivery for Agencies, Programs and Teams (ADAPT) Committee*

The NDIA ADAPT collaboration among industry stakeholders aims to establish harmony and common practices to drive positive change, with a focus on the integration of agile practices in hardware and manufacturing. NDIA emphasizes the importance of alignment and a culture of collaboration to achieve the goals of ADAPT. The working group is addressing challenges and developing principles and practices called Industrial DevOps, emphasizing value flow, multi-horizon planning, data-driven decision-making, and speed and modularity in architecture. ADAPT recognizes the need to integrate hardware and involve hardware teams, removing dependencies and defining interfaces to increase independence. The organization prioritizes training the workforce, transitioning them into an agile environment, and embracing continuous improvement to deliver value and field capabilities while being responsive to changing tactics.

Featured Talk and Q&A: DevOps Is Not Enough, *LTC Michael Tanner, PhD,* *Air Force Life Cycle Management Center (AFLCMC)*

LTC Tanner used a historical example to highlight the effectiveness of an agile and threat-based acquisition approach, emphasizing the need for a driving force to propel progress. The importance of a whole-of-nation effort and the rapid production achieved during a critical period demonstrate the benefits of pressure and competition. Communication and interoperability challenges, as well as the importance of next-generation platforms and kinetic effects, were discussed. LTC Tanner emphasized the key areas of speed, quality, focus, and collaboration, highlighting the need to incorporate quality into the certification process from the beginning and to work in small, iterative processes to ensure progress. The concept of industrial DevOps was presented as a means to bridge the gap between agile methodologies and real-world implementation. The importance of establishing appropriate metrics and adapting to the needs of various types of warfighters is emphasized in this approach.

Keynote and Q&A, *Dr. George Ka'iliwai III,* *U.S. Indo-Pacific Command (USINDOPACOM)*

Dr. Ka'iliwai, as the Director, Requirements and Resources (J8), US Indo-Pacific Command, focused on the DoD decision support system and advocated for critical joint warfighting requirements. The lack of joint focus and coordination in acquisition efforts poses a significant issue, hindering the combatant commander's ability to effectively execute operations. To make hardware acquisition more agile, Ka'iliwai emphasized the need to consider the end user, deliver capabilities rapidly, and adopt a different mindset, potentially drawing insights from commercial solutions. US Indo-Pacific Command engages with the acquisition community, particularly the US Space Force, to get closer to the warfighter and address hardware requirements. Innovation, disruption, and modernization are key areas of focus, with efforts to foster innovation through collaborations with research centers. Improving the decision support system and overcoming challenges in transitioning ideas into operational capabilities are crucial for successful modernization.

Breakout Session Summaries

Summaries from Day One (April 18, 2023)

Agile Development of Hardware-Reliant Systems as viewed by Systems Engineers, Lead Systems Integrators (LSIs), and Commercial High-Technology Companies was discussed in separate breakout sessions for each perspective.

Systems Engineers: *Modeling and Simulation enables access to hardware-driven capability before we "bend metal" – let's iterate while the hardware is still represented as software.*

Participants in the session discussed the importance of simulation and modeling when building anything. Different perspectives of the approach included a range of communities spanning airborne systems, ships, and other platforms. Speakers described the use of Virtual Reality (VR) environments to enable spatial orientation to assess task flow for platforms like the operation of aircraft carriers – where the movement of heavy equipment is critically important – to the design of airborne platforms where Computational Fluid Dynamics plays a prominent role in making design decisions. Hence, simulation is vitally important for designing advanced systems and can be used well before hardware engineers start "bending metal."

Also discussed was the importance of simulation in requirements elicitation and refinement, as well as for testing. The portability of the simulations to different platforms within the development environment (e.g., a laptop, or hardware-in-the-loop test lab) was mentioned as a potential barrier in some cases. In addition, the availability and importance of real-time emulations were discussed, specifically, the value of a real-time emulation to engage decision-makers with a demo of capabilities.

Finally, participants discussed the complexity and difficulty with computing ROI. Saving schedule and cost by reducing later rework is a good outcome achieved by testing in a virtual environment, but the benefit of greater clarity on requirements and design tradeoffs may not be easily represented through an ROI. Thus, the participants suggested that ROI may not be the correct figure of merit to use for attempting to justify building environments to explore requirements and design tradeoffs consisting of software and hardware in the loop systems.

Lead Systems Integrators: *Most often, hardware is a focus for supply chain – as the LSI is in a position to assemble hardware components more than to bend the metal and manufacture parts – so how can we do agile supply chain?*

Additive manufacturing examples to support prototyping during development were contrasted with larger-scale applications. Examples of production applications like "Just In Time Battle Field Production" seen on some warships are also found in niche segments of the automotive industry. The limiting factor for these applications appears to be in material science, availability, and the speed of manufacturing.

It was observed that prototyping applications may be favored because they may not require the same highly robust materials expected in production. For most traditional manufacturers, the DoD market may not be a sufficiently lucrative market. Also, the optionality that may be perceived to exist through dual-use designations may be more cost-prohibitive for the provider than is understood.

While "boutique suppliers" (micro-manufacturers) tend to be more nimble than larger firms, the ability of the firms using this business model to cope with the DoD's business rules and contracting approaches was raised as a concern. Further, it was observed that companies like Toyota actively invest in these providers, rather than take a limited transactional perspective.

Finally, the use of software-based models (including AI systems) in modeling data characterizing the supply chain engendered conversations about how world events (e.g., the COVID-19 pandemic) can drive a re-examination of the fundamental Lean Manufacturing concept (as lean inventories turned to devastating shortages).

Commercial High-Technology Companies: *It's much more about flexibility in the manufacturing perspective, as they tend to prefer doing more of the metal bending, and when they use suppliers, they place high demands and have low tolerance for risk. It's more about the agility (and maturity) of the manufacturing process.*

Managing the tension between "freezing the design" to obtain a high-confidence production schedule and "iterating the design" to increase some aspect of performance was prominent in this discussion session.

An innovation that can increase capacity, reduce weight, or enhance some key performance attribute has real economic value. Yet, missing a promised "launch date" has the potential downside in that it can often stifle innovation. This balance is also related to the anticipated scale of production.

When only one or two articles are produced, the risk-benefit tension is evaluated differently than when a factory producing hundreds (or thousands) of articles per month must be designed and built. Hence, the prevalent economic model takes a different form in commercial markets as compared to the DoD.

Venture capitalists aggressively fund innovative product designs, with the expectation of a large payoff from success (and a carefully assessed risk of loss). DoD programs operate with a model that strives to constrain production costs with aggressive affordability goals attempting to be mindful of taxpayer dollars.

The development organizations in these two settings must thrive under substantially different models. Further, the need (or not) for certification brings another key influence into the list of competing priorities (tensions) that must be managed. For many safety-critical cyber-physical systems, a complete end-item (finished system) is a prerequisite to certification.

Hence, design reliance on commodity hardware and a well-defined open architecture can help ameliorate the tendency toward an 'all-or-nothing' certification mindset. Gathering operational data from the system is one of the key items that is leveraged by organizations like Tesla™ and SpaceX to counter traditional models of certification.

Finally, the discussion turned to the emerging model of "continuous Authority To Operate (cATO)," which can be seen as a natural consequence of software's transition to DevSecOps "cloud-based" development environments. Participants indicated that this software development mindset is starting to find its way into the development and fielding of hardware-reliant systems.

Summaries from Day Two (April 19, 2023)

The focus of Day 2 breakout sessions was to probe how Agile Development of Hardware-Reliant Systems is enabled by key technical and environmental influences.

Modular Open Systems Architectures (MOSA) *facilitate a partitioning of capabilities in ways that greatly aid in defining incremental approaches to capability delivery. At the same time, the expectation of incremental delivery enables acquirers to sharpen the focus on MOSA and open themselves up to a larger pool of industrial providers. The integration of different types of components (Hardware, Software, Firmware) can be made more predictable in this way as well.*

Several economic arguments in support of MOSA focused on the buyer-side of the business relationships as seen in the DoD.

In this session, participants voiced caution about the potential for considerations about Intellectual Property (IP) rights may influence participation of some development organizations. While having the effect of diversifying the pool of potential offerors in the long term, the approach may also lead to higher "up-front" investment costs. Depending on the technology, this IP-related tradeoff may prevent some offerors from participating in the DoD's solicitation.

Diversifying the community of potential offerors is a laudable goal for DoD, but the mechanism for achieving it may not be appropriate for every program. Further, introduction of a required MOSA to an established platform is a different business model for the DoD than the adoption of a MOSA in a "greenfield"[1] engineering situation.

Emerging approaches for applying MOSA concepts to hardware are not common across the Defense Industrial Base (DIB); participants then brainstormed on what it will take to mature this approach. Working to "open up the market" for system elements with the most potential for future innovation seems most appropriate.

Finally, the participants recommended a "call to action" to foster communities of practice on MOSA for hardware. They also emphasized the need to publicize case studies of successful strategies with a DoD emphasis.

Acquisition Strategies *that leverage the agile mindset enable new program execution approaches and ways to buy-down technical risk. Iterating on the definition and implementation of Hardware-Reliant Systems is commonplace for modern high-tech product companies but may not be seen as commonplace in DoD Acquisition programs. Innovative acquisition strategies are a key enabler for this new way of working.*

This session drew a large number of participants, many with substantial experience in acquisition (both government and industry). Brainstorming on an agile "Hardware Acquisition Pathway," the group captured a list of unique hardware attributes, including component lead times, critical system integration labs, and certification requirements.

These topics and others would be considered in formulating a new pathway and could potentially change Milestone B in significant ways. The contracting approach focused on outcomes would need to treat requirements in a different way than is prevalent today.

The session contained notably experienced acquisition experts who discussed the need for a "Minimum Viable Policy" that could be used to foster learning from pilot programs. Essential questions for each pilot to answer through such an effort were captured for later consideration when sponsorship for pathfinder programs is identified.

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[1] Greenfield is a term that indicates that the engineers are building something completely new, or so far removed from any predecessor design as to be considered a brand new design solution.

Next Steps

To follow through on the potential for more agile development of hardware-reliant systems, the DoD should:

- Establish a Center of Enablement within the DoD that establishes and evolves Agile and Digital Transformation engineering practices by acquisition programs. The center would address acquisition policy and law, guidance, workforce training, organizational practices, and acquisition tradecraft as well as the design and underlying architectures of systems being acquired.
    - o Review existing acquisition policy and law for language that would preclude being able to acquire systems in the manner discussed herein, and that would have immediate operational use by the warfighter.
- Continue research on the application of Agile concepts that go beyond the branded methodologies of narrow communities of practice. The diverse needs of DoD programs and others operating in highly constrained settings require considerations that are not often part of the industry trends that lead to popular methods and frameworks.
- Charter pathfinder programs executing innovations in Acquisition Policy and Practice. Engage experts who will coach them with industry leading practices to acquire Hardware-Reliant Systems for the warfighter enabling Lean, Agile and DevSecOps approaches in development and delivery of those systems.
    - o Evaluate programs in a service with a Combatant Command that is willing to pilot the acquisition of a system using approaches that maximize the benefits of agile.
    - o Identify specific acquisition questions to be answered by these pilots.
- Collect lessons learned from DoD programs pursuing agile in hardware-intensive systems to identify, characterize, formulate, and codify best practices, lessons, foundational principles, and roadmaps for future DoD pursuit of agile systems development and enterprise transformation.

Conclusions

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!

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 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.

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 by the participants.

Our reasoning for the explicit inclusion of this new principle is that almost all software-intensive systems in use today include by design, built-in test (BIT) capabilities to diagnose the state-of-the-system during startup or while in operation to assist in trouble shooting. Many agile development approaches presented at the workshop use “test-driven development,” where the test is written prior to or in parallel with the software.

Workshop participants described similar concepts for hardware-reliant systems, i.e., the system’s maturation is accomplished with the understanding that it is being tested while being designed and “operated” in a manner to optimize the engineering learning process. “Shift learning to the left” appropriately captures this mindset.

This mindset, however, tends to be contrary to the ultra-conservative reliance on maximizing the quality of the design prior to building it, with very little to no tolerance for course-corrections to the design. The agile mindset integrates maximum information gathering from tight experimental design-implement-test cycles that integrates the end-user into the process for feedback and learning from potential failures.

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.

Appendix A: Workshop Organizers

Workshop Technical Leads:

- **Mr. Tom McDermott,** *SERC Chief Technology Officer, Stevens Institute of Technology*
- **Mr. Will Hayes,** *Principal Engineer, Software Engineering Institute, Carnegie Mellon University*
- **Dr. Douglas Buettner,** *AIRC Deputy Chief Scientist, Stevens Institute of Technology*

Moderators:

- **Dr. Philip Anton,** *Stevens Institute of Technology*
- **Dr. Douglas Buettner,** *Stevens Institute of Technology*
- **Mr. Will Hayes,** *Software Engineering Institute, Carnegie Mellon University*
- **Dr. Michael Orosz,** *Information Sciences Institute, University of Southern California*
- **Ms. Linda Parker Gates,** *Software Engineering Institute, Carnegie Mellon University*

Report Authors:

- **Mr. Tom McDermott,** *Stevens Institute of Technology*
- **Ms. Megan Clifford,** *Stevens Institute of Technology*
- **Dr. Douglas Buettner,** *Stevens Institute of Technology*
- **Mr. Will Hayes,** *Software Engineering Institute, Carnegie Mellon University*

Appendix B. Acronyms and Abbreviations

ACAT	Acquisition Category
ADAPT	Agile Delivery for Agencies, Programs and Teams
AIRC	Acquisition Innovation Research Center
API	Application Program Interface
ATO	Authority to Operate
cATO	Continuous Authority To Operate
CMU	Carnegie Mellon University
DAS	Defense Acquisition System
DIB	Defense Industrial Base
DevSecOps	Development, Security and Operations
DoD	Department of Defense
HW	Hardware
IP	Intellectual Property
MBSE	Model Based Systems Architecture
MOSA	Modular Open Systems Approaches
MTA	Middle-Tier Acquisition
NDIA	National Defense Industrial Association
OUSD(A&S)	Office of the Under Secretary of Defense for Acquisition and Sustainment
OUSD(R&E)	Office of the Under Secretary of Defense for Research and Engineering
ROI	Return on Investment
SEI	Software Engineering Institute
SERC	Systems Engineering Research Center
SOCOM	Special Operations Command
SW	Software
SWA	Software Acquisition
USINDOPACOM	U.S. Indo-Pacific Command
VR	Virtual Reality

AN INTERACTIVE WORKSHOP | APRIL 18-19, 2023

Agile Development of Hardware-Reliant Systems

DAY 1

7:30 AM	**Registration and Breakfast**
8:30 AM	**Welcome** ***Mr. David Cadman, SES*** *Director for Acquisition Data and Analytics, Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S))*
8:35 AM	**Agenda Review and Keynote Introduction** ***Dr. Philip Antón*** *Chief Scientist, Acquisition Innovation Research Center (AIRC)*
8:45 AM	**Keynote and Q&A** ***Mr. Jim Smith*** *U.S. Special Operations Command (SOCOM)*
9:30 AM	**Featured Talk: Research & Engineering (R&E) Software Strategy** ***Mr. Allan Dianic*** *Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E))*
10:00 AM	**Break**
10:30 AM	**Featured Talk and Q&A: Agile Across a Large DoD HW/SW Program** ***Ms. Brigid O'Hearn*** *Software Engineering Institute, Carnegie Mellon University*
11:10 AM	**Featured Talk: Agile in HW-Reliant Systems** ***Ms. Robin Yeman*** *Consultant*
11:50 AM	**Featured Talk and Q&A: SAFe Methodology in HW-Reliant Systems** ***Dr. Harry Koehnemann*** *Scaled Agile, Inc.*
12:30 PM	**Lunch and Networking**
1:30 PM	**Keynote and Q&A: MBSE Mis-use Cases** ***Mr. Will Hayes*** *Software Engineering Institute, Carnegie Mellon University*
2:15 PM	**Breakout Sessions**
4:30 PM	**Debrief from the Day** ***Mr. Will Hayes*** *Software Engineering Institute, Carnegie Mellon University*
5:00 PM	**Reception and Networking**
6:00 PM	**Adjourn for the Day**

DAY 2

7:30 AM	**Registration and Breakfast**
8:30 AM	**Welcome** ***Mr. Tom Simms*** *Acting Principal Deputy Director, Systems Engineering and Architecture (SE&A), Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E))*
8:35 AM	**Agenda Review and Keynote Introduction** ***Ms. Anita D. Carleton*** *Software Solutions Director, Software Engineering Institute, Carnegie Mellon University*
8:45 AM	**Keynote and Q&A: Industry Perspective** ***Dr. Jeff Boleng*** *Joby Aviation*
9:30 AM	**Featured Talk: Agile Methods in DoD Acquisition** ***Mr. Sean Brady*** *Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S))*
10:00 AM	**Break**
10:30 AM	**Featured Talk and Q&A: The Agile Program Office** ***Dr. Michael Orosz*** *Information Science Institute, University of Southern California*
11:10 AM	**Featured Talk and Q&A: Engineering in an Agile Culture** ***Dr. Suzette Johnson*** *NDIA ADAPT Committee*
11:50 AM	**Featured Talk and Q&A: DevOps is not Enough** ***LTC Michael Tanner, PhD*** *AFLCMC*
12:30 PM	**Lunch and Networking**
1:30 PM	**Keynote and Q&A** ***Dr. George Ka'iliwai III*** *U.S. Indo-Pacific Command (USINDOPACOM)*
2:15 PM	**Breakout Sessions**
4:30 PM	**Debrief from the Day and Forward Planning** ***Dr. Philip Antón*** *Chief Scientist, Acquisition Innovation Research Center (AIRC)*
5:00 PM	**Workshop Adjourned**

Appendix D. Workshop Participants

Full name	Organization	Title/Department
Allan V. Dianic	OUSD (R&E) Systems Engineering and Architecture (SE&A)	Director, Software Engineering / Systems Engineering and Architecture (SE&A)
Dr. Dave Gallop	Defense Acquisition University	Director, Acquisition Workforce Education Partnerships
Dr. Dennis McBride	OUSD(A&S)/ASD(A)/DASD(ADA)/AIRC	Director, Acquisition Innovation Research Center
Dr. Dinesh Verma	Stevens Institute of Technology/SERC	Professor/Executive Director
Dr. Doug Buettner	Stevens Institute of Technology	Deputy Chief Scientist/AIRC
Dr. Harry Koehnemann	Scaled Agile	Framework Methodologist
Dr. Jeff Boleng	Joby Aviation	Aircraft Cybersecurity Lead
Dr. Jerome Hugues	CMU/SEI	Senior Researcher / Model-Based Engineering
Dr. Kelly Alexander	OUSD R&E, SE&A	Chief Systems Engineer, SE Modernization (contractor support)
Dr. Michael McGrath	Stevens Institute	SERC/AIRC
Dr. Mike Orosz	University of Southern California Information Sciences Institute	Research Director/Research Professor
Dr. Philip Anton	Stevens Institute of Technology	Chief Scientist, AIRC
Dr. Rochelle Jones	George Mason University	Associate Chair/Systems Engineering and Operations Research Department
Dr. Ross Arnold	U.S. Army DEVCOM Armaments Center	Senior Scientific Technical Manager
Dr. Suzette Johnson	Northrop Grumman	NG Fellow, Lean-Agile
Elizabeth Torres	MITRE DTE&A	Project lead
Hasan Yasar	SEI|CMU	Technical Director / Continuous Deployment of Capability
Jitesh Panchal	Purdue University	Professor of Mechanical Engineering
John Robert	CMU Software Engineering Institute	Deputy Director, Software Solutions Division
Jon Schilder	Air Force Test and Evaluation	Senior Test & Eval Policy SME
Joseph Yankel	Software Engineering Institute	DevSecOps Initiative Lead - Software Solutions Division
Karen Thornton	GW Law	Adjunct faculty
Linda Parker Gates	Software Engineering Institute	Software Aquisition Policy and Practice Initiative Lead

Full name	Organization	Title/Department
Lt Col Michael Tanner	AFLCMC	Materiel Leader
Mr. David S. Cadman	OUSD(A&S)/ASD(A)/D(ADA)	Director, Acquisition Data and Analytics
Mr. James H. Smith	HQ USSOCOM	Acquisition Executive and Director
Mr. Mark E Krzysko	OUSD A-S	SES/Principal Deputy, Data and Analytics Acquisition Enablers
Mr. Mark Temnycky	OUSD(A&S)/ASD(A)/DASD(ADA)/AIRC	Project Controls Analyst, Acquisition Innovation Research Center
Mr. Max Rogozinski	Air Force Test & Evaluation	Senior AI Liaison and Cyber Test & Eval SME
Mr. Scott Brisbin	Northrop Grumman	Director of Engineering
Mr. Scott Lucero	Virginia Tech National Security Institute	Intelligent Systems Division
Mr. Sean Brady	OSD / A&S / A / Acquisition Integration and Interoperability (Ai2)	Deputy Director, Joint Interoperability; Sr Lead for Software Modernization
Mr. Sean Varela	Northrop Grumman Corporation	Director, Programs
Mr. Skip Hawthorne	OUSD(A)/Acquisition Data and Analytics	Deputy Director of Acquisition Policy
Mr. Tom Simms	OUSD(R&E), Systems Engineering and Architecture (SE&A)	Acting Principal Deputy Director
Mr. William S. Hayes	Carnegie Mellon / Software Engineering Institute	Principal Engineer, Agile Transformation Team lead
Mrs. Anita Carleton	Software Engineering Institute	Director of Software Solutions Division
Mrs. Monique Ofori	OUSD(R&E)	Systems Engineering
Ms Eileen Wrubel	Carnegie Mellon University Software Engineering Institute	Technical Director, Transforming Software Acquisition Policy & Practice
Ms. Brigid O'Hearn	Software Engineering Institute, Carnegie Mellon University	Software Solutions Division
Ms. Erin Fleming	OSD R&E	SE/A
Ms. Jazmine Garard	AIRC	Program Coordinator
Ms. Kara Pepe	SERC/AIRC	Director of Operations
Ms. Katherine Coyne	OUSD(A&S)	MTA Pathway Lead
Ms. Tara Kelly	SERC/AIRC	Research Project Manager
Philomena M. Zimmerman	Stevens Institute	SERC/AIRC
Robin Yeman	Robin Yeman LLC	Consultant