Putting Artificial Intelligence to Work: The Operator Decision Aid

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Synopsis

Advances in artificial intelligence and data analytics have unlocked new opportunities for progress in critical areas within the maritime domain. Over the past year, the U.S. Navy has initiated an Operator Decision Aid pilot project to apply rules-based navigation algorithms developed by the U.S. Defense Advanced Research Projects Agency (DARPA) and Office of Naval Research (ONR) to provide real-time recommendations to watch-standing teams on the Bridge and in the Combat Information Center. Recognizing the complexity inherent in the employment of artificial intelligence-based solutions, this paper will apply a multifactor framework developed by Crawford and Pollack (2004) to evaluate influential aspects of the project required to drive change, embrace complexity, and institute a culture of learning.

Keywords: Artificial Intelligence; Digital Systems Design; Total Ship Integration

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1. Introduction: Charting a New Course on Artificial Intelligence

"One of the biggest enablers is digital supremacy. Who can turn knowledge into decisions most quickly. The future is, who can get to the right decision most quickly. And what enables decisions? Turning a lot of data over to algorithms to crunch it to help give a decision – what most people call artificial intelligence. It's not a panacea, it's not perfect, it's not everything, but the concept of turning data into the right decision more quickly – or more importantly, pointing out when something is going south – is incredibly important."

Hon. Alan R. Shaffer
U.S. Deputy Undersecretary of Defense for Acquisition and Sustainment
February 14, 2019

Regarded as the father of Artificial Intelligence (AI), the visionary mathematician Alan Turing began theorizing the concepts of AI and Machine Learning as early as 1935. Turing believed it was conceivable for computing machines to learn from experience and solve problems by searching through the possible solution space to make decisions (Copeland and Proudfoot, 2000). AI development waxed and waned throughout the 20th century due to slow progress and inconsistency in funding for research and development; today, nearly 85 years after Turing first introduced the its concepts, AI has become a true technology disruptor with applications in both the civilian and military domains. With increased accessibility to cloud computing, upsurge in availability of data, and advancements in computing power and speed, AI is becoming increasingly infused into modern life. Using Google Maps on a smartphone to plot a driving route based on traffic and construction patterns is a prime example of everyday AI at work.

The U.S. Department of Defense (DoD) is heavily investing in AI technology to ensure a competitive military advantage against those who threaten global security. The 2018 DoD AI Strategy outlined the urgency of launching a set of initiatives for rapid incorporation of AI to enhance military decision-making and operations. The strategic pillars are represented in Figure 1 below:

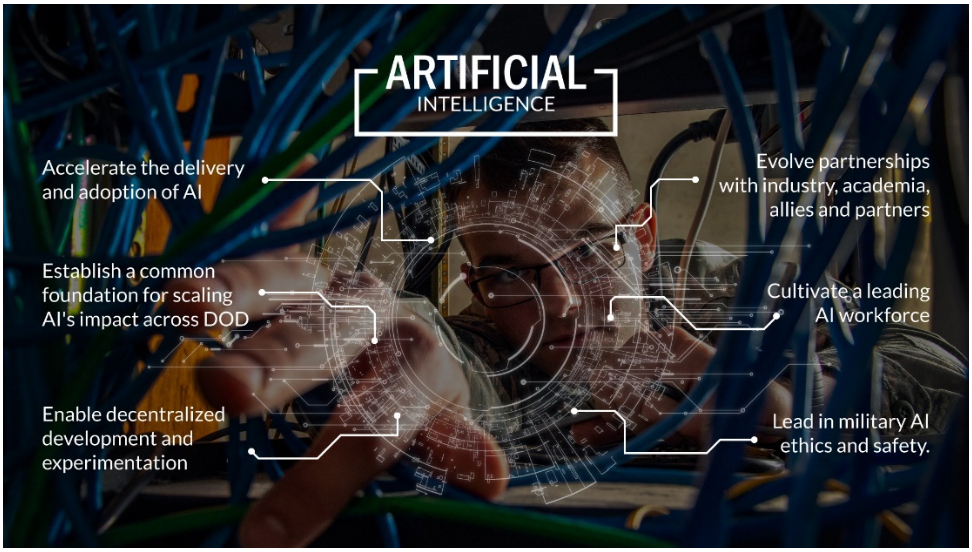

Figure 1: 2018 DoD AI Strategy Strategic Pillars

In concert with the DoD AI Strategy, the U.S. Navy is taking AI to sea. Specifically, a networking technology is being deployed across the Fleet that includes AI capabilities known as Consolidated Afloat Networks and Enterprise Services (CANES). Additionally, the U.S. Navy has begun hosting a series of HACKtheMACHINE events with the intent of infusing innovation from non-traditional partners into military applications. A recent event was held in Seattle, WA with a track focused on algorithm development to assist with collision prevention for human-operated and autonomous vessels. The U.S. Navy is recognizing that AI has the ability to unlock significant potential by enabling systems to handle larger volumes of data more efficiently and improve self-control and self-regulation of warfighting systems due to AI's inherent computing and decision-making capabilities.

A current key opportunity for Naval AI deployment is within ship navigational systems, a fundamental component of seamanship. Navigation challenges have escalated in recent years particularly due to increased shipping traffic density of the seas. According to the United Nations Conference on Trade and Development, maritime trade has increased 220% since 1975, resulting in highly dense waterways (Galdorisi, G., Goshorn, R., 2006). While the U.S. Navy has faced challenges with maritime navigation and situational awareness, science and technology efforts are focusing onAI solutions to enhance Sailors' navigation decision-making abilities. This current effort is known as the Operator Decision Aid (ODA) pilot project. Deploying this and similar types of rapidly evolving technology will require the U.S. Navy to embrace not only new technologies but new ways of thinking about technology insertion.

This paper will discuss the background of the ODA project, the AI technology being leveraged, and the application of a multidimensional framework to manage the effort to increase the probability of successful integration and deployment.

2. The Operator Decision Aid (ODA): Leveraging Advances in Artificial Intelligence

> *"As we go forward in this information age with artificial intelligence, with machine learning, bringing diversity and creativity to the human contribution to that is going to be decisive."*
>
> Admiral John Richardson
> U.S. Chief of Naval Operations
> February 13, 2019

The catalyst for the ODA pilot project was three U.S. Navy DDG 51 ship collisions in the last seven years resulting in significant loss of life and costly repairs. On August 12, 2012, USS PORTER (DDG 78) collided with the oil tanker M/V Otowasan in the Strait of Hormuz, causing major damage that cost the U.S. Navy $49.4 million in repairs (LaGrone, S., 2013). The Navy now uses a simulation of the incident to teach lessons learned to ship operators. A second collision occurred on July 17, 2017, when USS FITZGERALD (DDG 62) departed Yokosuka, Japan for routine operations and collided with MV ACX CRYSTAL. The third collision occurred just weeks later on August 21, 2017 when USS JOHN S MCCAIN (DDG 56) collided with MV ALNIC MC in the Strait of Singapore.

In the months following these events, the U.S. Navy conducted a full investigation of the collisions and released a report stating, "The collisions were avoidable between USS FITZGERALD and MV ACX CRYSTAL, and between USS JOHN S MCCAIN and MV ALNIC MC." The investigations of the FITZGERALD and JOHN S MCCAIN collisions cited a lack of knowledge of the International Rules of the Nautical Road, lack of radar training, and, due to the ships not operating at a safe speed appropriate to the number of other ships in the immediate vicinity, failure to maneuver early enough. Additionally, leadership failing to sound the warning alarms and take proper action in extremis and crew fatigue played a role in the collision. Moreover, the report noted that command leadership "did not foster a culture of critical self-assessment" (LaGrone, S., Warner, B., 2017). The U.S. Navy is using much of these findings to improve crew training and qualifications; however, there are also opportunities to utilize advanced technology to help increase the situational awareness of ship operators and reduce potential ship collisions.

In response to these mishaps, the U.S. Navy is leveraging AI-based technology currently used on U.S. Navy autonomous surface vessels to rapidly develop an ODA prototype. This prototype is intended to provide ship operators real-time maneuvering recommendations to reduce the likelihood of future mishaps at sea. In particular, the objective is to provide recommended course and speed in critical situations where high/unfamiliar traffic patterns, reduced visibility, and engineering casualties require immediate and accurate decision making under stressful conditions. The intention of the ODA is to use data analytics to enhance operator situational awareness, reduce operator cognitive load, and provide a real-time safe track in a dynamic traffic environment.

The rapid technology development leverages the International Maritime Organization (IMO) Regulations for Preventing Collisions at Sea (COLREGs) compliant autonomy algorithms developed by the US Defense Applied Research Projects Agency (DARPA) and the US Office of Naval Research (ONR) for SEAHUNTER Unmanned Surface Vessel. SEAHUNTER became the first ship to autonomously complete a round trip transit from California to Hawaii in December 2018 by successfully navigating the route without a single crew member onboard, with the exception of short duration boarding from escort vessel personnel to check on systems such as electrical and propulsion. Given the proven success of SEAHUNTER, the science and technology community recognized the opportunity to take advantage of this technology for ODA development.

To enable accelerated acquisition of this critical capability, the U.S. Navy has partnered with the same industry partner who developed SEAHUNTER autonomy algorithms via a simplified contracting process. The U.S. Navy worked with this industry partner to facilitate a workshop with ship operators aimed at obtaining early feedback for the ODA design. The workshop was conducted in the Fleet concentration area of San Diego with participants encompassing 40 operators from seven ships along with representatives from academia, industry, and various Navy commands. The workshop breakout teams were intentionally comprised of individuals from different backgrounds and experiences to widen the scope of input.

A design-thinking process was constructed for the workshop to spark creativity and innovation in solution development. The workshop facilitators encouraged divergent thinking, and, throughout the process, a prioritization scheme was utilized to identify ODA design themes valued by operators. The ideas converged into four categories, all of which either enable or are a direct result of AI:

- Improve Situational Awareness
- Autonomy Features and Functionality
- Information and Sensor Integration
- Decision Aids and Displays

Merging desired design output from the workshop with AI technology available from SEAHUNTER algorithms, the U.S. Navy is currently in process of developing the ODA prototype. An Agile management approach is being deployed as part of the rapid prototyping process to emphasize continuous user involvement and provide faster delivery of results. Iterative and incremental delivery of the ODA will be provided to the users, and their feedback will be leveraged to refine a collaborative design throughout the Agile development process as illustrated below in Figure 2.

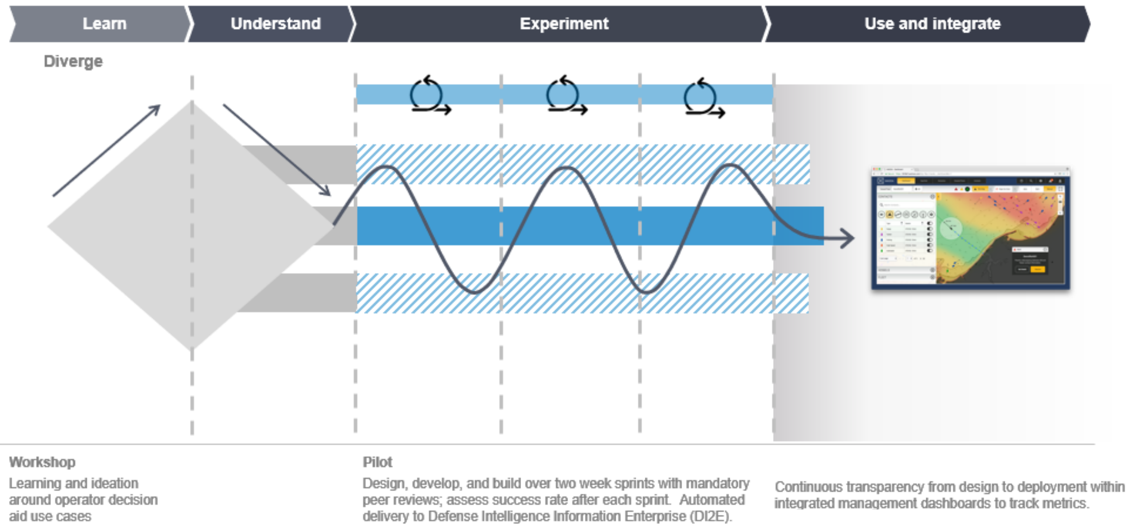

Figure 2: Agile Development Process

3 Moving to a More Adaptable and Agile Development Construct: Introducing a New Model

"AI tools are everywhere. Machine learning is rapidly accelerating all around us."

Admiral William Moran
U.S. Vice Chief of Naval Operations
February 13, 2019

As AI-based systems become more integral to naval operations, meeting the challenge of rapidly fielding these capabilities will require new ways of thinking. Viewing Systems Engineering as both an art and a science is emphasized throughout Hitchins' (2007) S*ystems Engineering: A 21st Century Systems Methodology* where systems engineering is defined as "creating whole solutions to complex problems" (pp. 91). This perspective builds upon Checkland's (1981) formative work in distinguishing between hard and soft-systems thinking, two distinct problem structuring methods. The DoD's traditional lifecycle approach in guiding programs from initial formulation into implementation and the Systems Engineering "V" Model, described in INCOSE's (2014) systems engineering body of knowledge, are important contributions to the field. However, both are deeply rooted in traditional hard-systems thinking and not sufficiently responsive to innovative projects such as ODA, which seeks to employ both an Agile approach to improve the process of delivery while promoting collaboration between Development, Security, and Operations (DevSecOps) teams. If the only tool provided to managers is the "hammer" of hard-systems approaches, it should not be surprising that "every problem looks like a nail" (Maslow, 1966). Unilaterally employing hard-systems approaches across all DoD programs often results in cost overruns, schedule delays, and programs falling short of realizing their full potential.

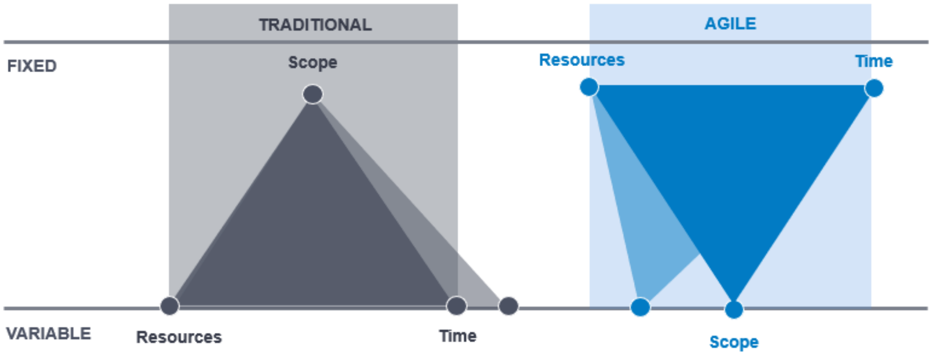

Figure 3: Traditional vs. Agile Approach

Recognizing the complexity inherent in the "real world" employment of both Agile and DevSecOps practices for the ODA pilot with fixed resource constraints and an accelerated timeframe (Figure 3), this paper explores the applicability of new approaches. Transitioning from the DoD's well-defined but rigorous hard-systems military standards (see, for example, MIL-STD-1521B Technical Reviews and Audits for Systems, Equipment, and Computer Software) to more adaptive practices such as Agile and DevSecOps provides the ability to meet the challenges of the pilot project by driving change, embracing complexity, and instituting a culture of learning (Checkland and Scholes, 2001). Crawford and Pollack's (2004) seven-dimension framework for evaluating influential aspects of projects is applied throughout the remaining sections of the paper to categorize the emerging dynamics and complexity of the ODA pilot project. Finally, Figure 4 distinguishes key attributes across these seven dimensions, highlighting the importance of adaptive management approaches to structure team discussion and determine the most useful methods and approaches as discussed in the following section (Crawford and Pollack, 2004; Pollack, 2008).

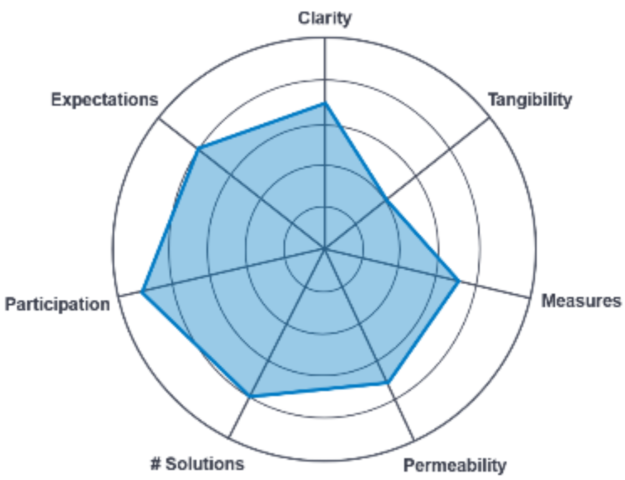

Figure 4: Seven Dimension Framework

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Goal/Objective Clarity. The U.S. Navy has outlined aggressive goals and objectives for incorporating advanced analytic tools such as AI as part of broader goals to "design and implement a comprehensive operational architecture to support Distributed Maritime Operations (DMO)." The updated *Design for Maintaining Maritime Superiority* expanded upon broader concepts established in the original 2016 release, emphasizing the need to provide "accurate, timely, and analyzed information to units, warfighting groups, and Fleets." Investments in AI will allow operational commanders to rapidly employ emergent capabilities that enhance the human-machine teaming required to maintain warfighting superiority. The U.S. Navy's Chief of Naval Operations, Admiral John M. Richardson, recently noted the need for "artificial intelligence, learning algorithms, figuring out the optimum way to team together the people, our Sailors and machine assistance" by leveraging the growing amount of sensor information with the vast amounts of available data storage. While the U.S. Navy's goals and objectives for leveraging investments in advanced analytic tools such as the ODA pilot are impressive, they are not as clearly defined as traditional projects managed by organizations responsible for developing, acquiring, and fielding major defense acquisition systems. Pollack (2008) summarized the challenges of articulating goals and resulting benefits, particularly within public sector programs where "continually reviewing and redefining goals" throughout the lifecycle and adopting more adaptive problem-solving methodologies may be the most appropriate management approach.

Goal/Objective Tangibility. Realizing the full potential of advancements in AI and data analytics as well as pairing these technology solutions with operators will require a flexible approach that supports rapid development and pilot ODA capabilities while translating ambiguous concepts into operational reality. As discussed in previously herein, a ship operator's ability to determine the best possible course of action given mission parameters is key within the maritime domain, particularly in situations where unfamiliar ship traffic patterns, reduced visibility, and engineering casualties require immediate action. Additionally, the U.S. Navy must consider operator feedback from a generation of Sailors for whom Information Technology has been a ubiquitous part of everyday life. Determining the tangibility of the U.S. Navy's goals, particularly during the early planning stages of the ODA pilot project, will prove challenging. This is reflected in Crawford and Pollack's (2004) emphasis on the connection between goal clarity and tangibility. For example, during situations where mission parameters evolve rapidly and Sailors are subject to cognitive overload, improving situational awareness by employing advanced analytic tools to provide real-time track recommendations in a dynamic environment will be required; however, quantifying the benefits of leveraging advanced AI to ensure seamless integration of watch-standing teams on the Bridge and in the Combat Information Center can be difficult. As a result, goals will remain intangible for many emerging AI applications such as ODA as it provides a support function for ship watch-standing teams around the world.

Success measures. Traditionally, program success has been evaluated through measures of cost, schedule, and technical quality largely ignoring aspects such as improved operator situational awareness by leveraging advanced analytic tool advancements to improve safety of navigation, seamanship, and ship handling performance. These traditional metrics assess progress by satisfying predetermined requirements and scheduled delivery, regardless of potentially evolving customer needs, fall short in effectively assessing the delivery of performance. Locatelli (2014) argues that, from a Systems Engineering perspective, success needs to shift from this "triple constraint" to focus on successfully delivering systems that operate in a complex environment. Within this context, an important consideration the U.S. Navy has begun to explore is the paradigm required to shift from a traditional "require then acquire" mindset to one of "acquire then require." By delaying requirements definitions and not immediately locking into new rules-based navigation algorithms into a formal program of record, but rather, implementing success metrics that support Agile values and the customer need, the pilot project will be able to quickly incorporate emerging operator requirements throughout system development. Ultimately, as technologies such as ODA are transitioned into the Fleet, traditional measures of success will need to be reevaluated as the U.S. Navy obtains additional operator feedback and begins to embrace the culture shift in traditional systems engineering and program management practices required to rapidly introduce and experiment with new capabilities.

Project Permeability. The accelerating rate of change has rendered once technologically advanced navigation capabilities obsolete as well as prioritized the need to safeguard against an adversary gaining control of AI-enabled systems, such as ODA, open architectures, seamless networking, and robust cybersecurity, perforating previously well-defined boundary conditions and blurring the lines between traditional program boundaries. Within the context of the ODA pilot project, Open Systems Architecture (OSA) and standards compliance will provide an effective framework to incorporate "best of breed" solutions, avoid vendor lock, support fault tolerance with plug-in capabilities similar to the way that smartphones seamlessly and securely integrate new applications (DoD 2013). Promoting modular and distributed functionality will also simplify testing, verification, and validation, allowing systems engineering and software development teams to focus on repurposing proven capabilities rather than developing bespoke solutions. For the ODA pilot project, along with many projects in the U.S. Navy, there are certainly influences outside of project control, leading to a permeable boundary, as Crawford and Pollack (2004) emphasize. Due to the high permeability of the project, it is crucial that a wide variety of stakeholders are included throughout the project to provide insight from multiple perspectives. As ship schedules are changed and systems that the ODA will need to integrate into are advancing, these stakeholders will play a vital role in developing a practical solution that will be fully integrated into the combat systems. A process engaging an Integrated Product Team (IPT) will enable the deliverables to be tailored to the changing environment as emergent knowledge is exploited. Finally, ensuring that projects such as ODA are highly resilient to cyberattacks and incorporate strong information assurance and anti-tamper (IA/AT) measures is an essential support component as cybersecurity teams continuously investigate challenges unique to systems enabled by artificial intelligence and vulnerabilities that could permeate across the force structure (Horowitz and Lucero, 2016).

Number of solution options.
Traditionally, project managers in the U.S. Navy are tasked with solutions or goals that they are expected to implement without the opportunity for questioning or discussion. While hard methods focus on efficient delivery of a single set solution, soft methods focus on debate and exploration of alternate solutions. With ODA, the three focus areas for decision aid development, hardware, human-machine interface, and autonomy implementation, inherently require varying levels of soft and hard methods. While the hardware and autonomy implementation will leverage previously developed algorithms and COTS solutions, the human-machine interface is the area that has a variable number of solution options with input required from the government and especially the operators themselves. The hardware and algorithms will be focused on efficient delivery of a set solution since this algorithm is being leveraged from the DARPA to an ONR-transitioned project and the hardware has a fixed and finite number of possible solution options; thus, a hard method is intrinsic to the delivery process. Conversely, the human machine interface will seek innovative solutions and ensure the best option is chosen following an exploration of alternatives, making the soft method most appropriate. Inputs from stakeholders will be of high value throughout the development of the ODA pilot project via an Agile approach. Effective management of these inputs will be key in filtering for relevance and importance while balancing innovation and exploration such that the elements most relevant to formulating an optimal solution are selected.

Table I Traditional vs Agile Development

	Traditional Development	*Agile Development*
Fundamental principles	Systems are fully specifiable, predictable, and are built through meticulous and extensive planning	High-quality adaptive software is developed by small teams using the principles of continuous design improvement, rapid feedback, and change
Management style	Command and control	Leadership and collaboration
Knowledge management	Explicit	Tacit
Communication	Formal	Informal
Desired organizational form/structure	Mechanistic (bureaucratic with high formalization) aimed at large organizations	Organic (flexible and participative encouraging cooperative action) aimed at small and mid-sized organizations
Quality control	Heavy planning and strict control. Late, heavy testing.	Continuous control of requirements, design and solutions. Continuous testing.

Adapted from Highsmith (2007) and Dyba and Dingsoyr (2008)

Degree of participation and practitioner role. As the U.S. Navy shifts towards a culture of high-velocity learning to pace with and enable innovation, there has been greater emphasis on program managers serving as facilitators who ensure active participation among interdisciplinary teams. As the U.S. Navy has been organized to manage platform-centric programs with subject matter experts assigned to individual commands, adopting a contingency approach (van Dock and Molly, 2008) represents a significant cultural change to traditional management structures. Over the next several years, introducing advanced analytic tools and piloting the ODA to maximize the investments in AI through underway prototype technology demonstrations will necessitate changes to streamline the ability to test, verify, and validate system capabilities across platforms ranging from the *STILETTO* fast attack craft to multi-mission *ARLEIGH BURKE* Class Guided Missile Destroyers. Embracing a facilitative role also includes establishing higher levels of trust with operators and external stakeholders. In order to maximize the potential of the ODA pilot project, broader adoption of highly coordinated teams will be needed to bridge gaps between organizations. This will require the reexamination of rigid systems engineering practices and traditional techniques for managing detailed system and component-level specifications as well as challenge legacy processes/procedures to manage team efforts with continuous transparency of the system integrator’s Agile development process and DevSecOps pipeline.

Stakeholder expectations. Managing stakeholder expectations at all levels is critical to rapidly develop and deploy the ODA in response to urgent operational needs. The existing system is well-suited for the bottom-right hand quadrant of Hayes and Wheelright’s (1979) product-process matrix where strict communication protocols with program stakeholders and standardized processes focus on managing the risk for continuous production systems. Traditional navy acquisition ship programs historically operated effectively within this model given the maturity of the design and evolutionary approach to support stakeholder expectations over the long service life of each platform. Legacy models, however, are not effective at sustaining the speed of advanced analytic tool developmentrequired for breakthrough systems enabled by AI to address emergent requirements from a diverse set of stakeholders. Wheelright and Clarke (1992) highlight that “successful breakthrough projects establish core products and processes that differ fundamentally from previous generations.” In fact, if the U.S. Navy does not respond to the CNO’s expectations to improve the speed from initial concept-to-deployment for breakthrough systems, efforts to implement a mature Agile methodology and DevSecOps pipeline to enable continuous integration and delivery will be sub-optimized.

Rapid experimentation is a key design principle the U.S. Navy is adopting to better align capability insertion with the speed of technology development. In contrast, systems engineering guidance within the U.S. DOD is largely based upon major defense acquisition programs with long expected service lives, emphasizing technical performance within well-defined cost and schedule constraints (DoD, 2017). CNO Richardson noted, “[T]hat environment needs to be a little more agile and perhaps a little bit riskier. Going through that, we actually gain confidence and field a much better tested product, so that when it goes forward into the fight, it's completely tested.” In order to meet the expectation of rapidly piloting the ODA, the U.S. Navy must regularly engage stakeholders at all levels to evaluate alternate system design, software development, and pilot processes. In contrast to monolithic ship acquisition programs where milestone decision gates and detailed monthly in-process reviews are standard, the ODA pilot project will provide full transparency and real-time access by U.S. Navy stakeholders to the development environment. This approach will help align stakeholder expectations to ensure the U.S. Navy and industry team is able to view early indications and warnings of the pilot project’s success, drill down to determine driving factors, rapidly deploy or redeploy engineering staff, and quickly incorporate user feedback.

4 Conclusion

With a vision of mitigating ship mishaps, the ODA pilot project is intended to leverage technology solutions to assist ship operators with navigation. It is a breakthrough initiative aligned with several of the U.S. DoD and Navy’s strategic priorities to promote accelerated acquisition, engage in rapid prototyping, and advance incorporation of AI. In addition, Agile management approaches are being incorporated for development of the prototype design. Beyond the specified goals of the project, the ODA development is pioneering the way for future innovative capability insertion. To this end, the U.S. Navy must re-think and adopt new program management processes to evolve from legacy hard system approaches in order to keep pace with innovation and rapidly advancing technology. Leveraging models like Crawford and Pollack’s seven-dimension framework provides structure amidst the ambiguity of complex and dynamic program management in an evolving environment where innovation, rapid prototyping, and speed to capability continue to emerge as the way of the future.

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