Unalone and Unafraid: A Plan for Integrating Uncrewed and Other Emerging Technologies into US Military Forces

BRYAN CLARK AND DAN PATT
 SENIOR FELLOWS, HUDSON INSTITUTE
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During the Cold War, the United States Department of Defense (DoD) led global research and development (R&D) and in the process created what are now commonplace technologies, including the internet, precision weapons, and the global positioning system. However, since then the DoD has struggled to incorporate new advancements as initiatives to transform the force or implement a new offset strategy have failed to substantially change the US military's design or capability development processes. In large part, the DoD’s adoption difficulties result from the center of technological innovation shifting from governments to the private sector, increasingly making the military a technology customer rather than a creator. This is the case with artificial intelligence (AI) and uncrewed systems, which are already upending long-standing approaches to modern warfare. The challenge of integrating these new technologies, many of which are commercially derived, therefore provides a good case study for how the DoD could reform its processes and organizations for innovation. To that end, this study evaluates how the US military could realize more timely development, deployment, and integration of relevant uncrewed systems, and illustrates its proposed methods using examples from the US Navy.

The Navy and DoD will need the operational advantages that AI-enabled uncrewed vehicles could offer. Against a resident major power like the People’s Republic of China (PRC), the US military cannot continue to rely on its historical dominance to deter and defeat aggression. Instead, the DoD will need to attack the People’s Liberation Army (PLA) strategy of system destruction warfare by fielding a force that is less predictable, more adaptable, and increasingly resilient. Uncrewed systems could enable such an approach by unlocking the operational innovation of US servicemembers, who could—like their counterparts in Ukraine today—use uncrewed systems to grow the variety of tactics and effects chains that they can employ, which

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could undermine PLA planning and concepts and afford US forces the capacity to sustain a protracted conflict.

The ability of uncrewed systems to provide resilience and adaptability depends on scale. A small fleet of vehicles cannot be simultaneously applied against multiple mission threads or effects chains and will lack the capacity to support extended operations. Uncrewed systems can enable scale by foregoing robust self-defense and focusing on a narrow set of functions to lower their cost and complexity. These limitations will require that uncrewed systems be combined with other uncrewed systems and crewed platforms in systems of systems (SoS), which could exacerbate the US military’s long-standing struggles to integrate forces between and within each service branch. Realizing the benefits of uncrewed systems will therefore demand that the DoD establish routinized processes for integrating new mission threads and SoS. Otherwise, the US military services will only be able to field individual uncrewed systems that replace crewed platforms in existing use cases.

US military services are already attempting to improve their ability to integrate SoS through initiatives in experimentation, rapid acquisition, digital interoperability, and Joint All-Domain Command and Control (JADC2). However, as this report describes for the US Navy, these efforts tend to focus on long-term service objectives rather than near-term operational problems and use a top-down process of systems engineering to guide requirements for future capabilities. This traditional approach assumes that the US military has the time to develop new systems and retains a substantial technological edge over its rivals, but neither condition is likely to endure in the context of the US-PRC competition.

To bring uncrewed systems into the force more quickly and gain the resulting operational advantages, the DoD will need to flip its traditional acquisition approach and adapt US military tactics or mission threads so they can integrate uncrewed systems that are available today. This bottom-up method of “mission integration” contrasts with the DoD’s predominant approach of systems engineering and reflects best practices emerging in commercial manufacturing or distribution, where the fastest and most effective way to assimilate robotics is to adjust the organization’s workflow as opposed to developing robots that replace humans in existing workflows.

To evolve the DoD’s current processes and implement mission integration, this study recommends the following reforms:

1. **Formalize a mission integration process that would conduct the functions of SoS development described in chapter 4 to address near-term combatant commander operational problems.**

   Each of the services and the Office of the Secretary of Defense (OSD) should conduct six functions to more quickly field new SoS, which will almost universally incorporate uncrewed elements:

   - **Problem definition**—working with operational commanders to identify and articulate their key operational problems
   - **Solution development and experimentation**—assessing ways to address operational problems using new concepts and fielded or available technology
   - **Material procurement**—obtaining needed systems and vehicles for experimentation and initial fielding of prototype SoS
   - **Digital integration**—combining SoS elements in mission threads that are useful in military contexts
   - **Resourcing and requirements**—Funding mission integration activities and validating the results of successful prototype experiments to enable acquisition
   - **Operational refinement**—Assessing prototype SoS in the field to validate requirements and refine systems over time.

   While mission integration would be the main path for fielding new uncrewed systems, the services should continue their processes of systems engineering and requirements generation to satisfy projected long-term needs for crewed platforms and other capital investments.
2. Establish an Innovation Office as the resource sponsor for SoS development and manager of the mission integration process.

The Innovation Office would need funding across multiple appropriation categories and the ability to validate requirements in concert with the appropriate service or Joint Staff offices. In the near term, the DoD could create an Innovation Office by reorganizing existing service or DoD organizations and their associated funding. Over the longer term, the DoD should assign the Innovation Office funding in broad program element (PE) lines, like those it uses in defense-wide R&D or those that the portfolio budgeting model proposes, to enable a prompt transition of promising SoS into procurement and fielding.

3. Create DevOps program manager (PM) roles in service program executive offices (PEOs) and in OSD.

DevOps PMs would help synchronize and accelerate the mission integration process by contracting for a variety of services and procurement or by moving funding to other government offices to support analysis and experimentation. The services should establish DevOps PMs to support mission integration efforts within each PEO that oversees uncrewed systems, and OSD should establish a PM role for joint mission threads within the Office of the Under Secretary for Research and Engineering (OUSD R&E) or the Office of the Under Secretary for Acquisition and Sustainment (OUSD A&S).

The establishment of DevOps PM roles will mark a significant cultural shift by bringing acquisition professionals into the experimentation and requirements process. However, connecting experimentation and acquisition is appropriate when available technologies are able to meet current and near-term military needs and when a more rapid introduction of new capabilities is essential to gaining an operational advantage.

4. Create ecosystem PM roles in service PEOs and in the OSD.

Software is increasingly the source of military capability and advantage in new weapons, mission systems, and vehicles. Software is also the mechanism by which military forces integrate today, much as past generations integrated through doctrine and procedure. The DoD should establish PMs in each acquisition PEO to manage the development and maintenance of SoS software environments. Ecosystem PMs would own government interfaces that connect vehicle, mission system, and command and control (C2) software and would oversee the integration of new systems into the ecosystem. Rather than taking more software development work into the government, the establishment of ecosystem PMs would enable the government to manage and oversee software development efforts by vendors, including software factories that maintain command, control, and communications (C3) environments and execute gauntlets through which new system providers demonstrate their ability to digitally integrate with the ecosystem.

Conclusion

In an environment where dominance is no longer a given, the US military needs to return to operational innovation. Historically, US forces have excelled when given the tools and processes to improvise and be creative. Many of the pieces they need to enable effective innovation through mission integration are already in place. Accelerating and realizing the benefits of uncrewed systems will require better orchestration and execution of these activities to solve today’s operational problems. If the Navy and DoD fail to do so, they may miss their best opportunity to gain an enduring advantage against peer opponents like China.
During most of the twentieth century, the US government, especially the Department of Defense (DoD), was the nation’s—and for a time the world’s—predominant technology developer. Because new capabilities emerged almost exclusively from a DoD-controlled pipeline, they could be designed to work with other elements of the force. The US military exploited this built-in interoperability to rapidly introduce new technologies for communications, sensing, countermeasures, and weapons across the force as it recapitalized World War II-era ships, aircraft, and vehicles. And if a new system was not technically interoperable, the DoD could integrate it through new training and procedures in the days before ubiquitous networks demanded widespread machine-to-machine communication.

Since the end of the Cold War, the US military has struggled to adopt new technologies. Reductions in military spending, defense industry consolidation, and the rise of commercial research and development (R&D) turned the DoD into a minority sponsor of US innovation by the 2010s. Unable to replace the force en masse as it did during the twentieth century, the US force today largely consists of ships, aircraft, and armor designed during the twentieth century and carrying a mix of new and old mission systems and weapons. Capability improvements within realistic budgets will increasingly depend on commercial providers with access to private capital and innovation pipelines that dwarf those in the DoD R&D ecosystem. Exploiting commercial advancements and incorporating new technologies into today’s eclectic US military will therefore demand a dedicated effort to

identify and integrate the combinations of units and systems that provide the most benefit to US forces in priority operations.³

The DoD has most often used commercial technologies in mission systems like sensors, radios, and electronic countermeasures, which can tap advancements in software, radiofrequency engineering, and networking emerging from the telecommunications industry. However, the commercial market for uncrewed systems is now rapidly growing, offering the DoD an opportunity to exploit privately funded innovation in vehicles, actuators, and guidance systems as well. The continued march of commercial advancements into new sectors could allow the US military to focus its own R&D on highly specialized military platforms and weapons while harvesting other capabilities from commercial technology pipelines.

Pentagon leaders are aggressively pursuing a diverse array of uncrewed air, surface, and undersea systems, but those efforts that have transitioned into formal programs focus almost exclusively on intelligence, surveillance, and reconnaissance (ISR) missions.⁴ Despite numerous experiments, demonstrations, and competitions, the US military services have fielded only a few uncrewed vehicle programs devoted to more complex operations such as air-to-air warfare, anti-submarine warfare (ASW), electromagnetic warfare (EW), and strike or surface warfare.⁵

Although a cultural aversion to adopting uncrewed technology is certainly a factor, from a practical standpoint, integration challenges are the most significant impediment to the DoD using uncrewed systems for a broader array of applications outside of ISR. The US military’s thousands of uncrewed surface, air, and undersea vehicles can operate as standalone systems when conducting ISR, with their sensor data going to dedicated receivers for analysis and with dedicated operators planning or controlling their missions. In the limited circumstances when US forces use uncrewed systems for missions like EW or strike, they do so under the direct control of an operator and largely avoid interactions with other crewed platforms or forces.

The challenges and opportunities associated with uncrewed systems make them a useful case study in how the DoD should transform its processes and organizations to integrate new technologies into the force. Drawing on practices emerging from commercial robotics and innovation, this study evaluates how

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**Figure 1: System-level Value Proposition for Pursuing Uncrewed Solutions**

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<th>Enables Operational Risk-Taking</th>
<th>Unique Performance Characteristics</th>
<th>Reduced Cost</th>
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<td><strong>Standoff missiles</strong> are uncrewed vehicles that enable one-way missions</td>
<td><strong>Satellites</strong> are uncrewed vehicles that enable long-endurance exo-atmospheric ops</td>
<td><strong>Operational cost savings from reduced training, platform usage</strong></td>
</tr>
<tr>
<td>Can afford risk of loss</td>
<td>Size, packaging</td>
<td>Procurement costs (sometimes) from reduced size or life support requirements</td>
</tr>
<tr>
<td>Can afford probes and feints</td>
<td>Endurance, speed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Precision station keeping</td>
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Source: Authors.
the DoD could realize more timely development, deployment, and integration of relevant uncrewed systems. To make its analysis and recommendations more concrete, the study centers on the US Navy’s uncrewed system development efforts, although this report’s findings are relevant across the DoD.

The practicalities of integration may have limited the DoD’s use of uncrewed systems in the past, but new US military concepts continue to constrain uncrewed system use cases by treating them as extensions of crewed platforms or units. Efforts like the US Air Force’s Loyal Wingman or the US Navy’s Large Uncrewed Surface Vessel (LUSV) exemplify this reality. These manned-unmanned teaming (MUM-T) concepts generally exploit the systems-level characteristics of uncrewed vehicles to provide crewed units greater reach or persistence, as figure 1 summarizes. Because they do not carry human operators, even relatively expensive uncrewed vehicles are attritable from the DoD’s perspective, and they may be lost to combat or other exigencies with little regret.

Without the confines of human limitations, uncrewed systems can operate in unforgiving environments or circumstances such as space. And without human operators, uncrewed vehicles can be less expensive than their manned counterparts due to fewer requirements for life support, protection, live training, or multi-mission capability.

Using uncrewed systems to extend the reach and persistence of crewed units made sense during the post–Cold War era of US military dominance. The DoD was pursuing efficiencies that would allow a smaller force to sustain US security commitments while relying on a growing portfolio of uncrewed space and airborne sensors to support networked precision strike warfare. But against a peer competitor, the use of uncrewed systems as extensions of crewed units tends to perpetuate the limitations of crewed systems while failing to take advantage of the ability of uncrewed technologies to improve the force’s flexibility and resilience.

Individually, crewed multi-mission units are the most versatile elements of the US military. Warships, submarines, fighter squadrons, and infantry battalions can conduct offensive and defensive operations; sense, understand, and adapt to new conditions; and sustain themselves for a time. But in aggregate crewed units incorporate constraints that limit their adaptability and the range of options available to commanders. Crewed units are expensive to buy and maintain while costs for operator compensation continue to rise faster than defense budgets, leading the DoD to reduce its fleets of crewed ships and aircraft. Crewed units often require protection and logistics support for operations beyond a few days or in a contested environment, necessitating standardized force packages like carrier strike groups or brigade combat teams. And because they depend on human operators, crewed units tend to rely on relatively well-defined tactics that allow for commonality in training.

The US military’s pacing threat, the People’s Republic of China (PRC), has exploited the dependability of US force compositions...
and tactics in its concept of system destruction warfare, or systems warfare. Under this approach, the PRC’s People’s Liberation Army (PLA) assesses the systems of systems (SoS) US forces are likely to use in combat and the potential vulnerabilities in those systems. The PLA then develops and fields capabilities that can attack what it perceives as US weaknesses and undermine the ability of US and allied militaries to intervene on behalf of allies like Taiwan. For example, the PLA fields a variety of electronic warfare systems that target key US networks, such as Link-16 or the Wideband Global Satellite communication system. In implementing systems warfare, the PRC has exploited commercial and proliferated military technologies to undermine traditional US advantages in air defense, precision strike, and long-range power projection.

A fundamental driver behind the US military’s relatively stagnant force design and unimaginative use of uncrewed systems is its continued reliance on post–Cold War planning processes that assume it is and will remain the superior, if not dominant, force. This assumption gave rise to requirements and acquisition processes that attempt to forecast what the US military needs to stay ahead of opponents and methodically develop the requisite technologies and systems over a decade or more. The Joint Capability Integration and Development System (JCIDS) requirements process and DoD Directive 5000.01 acquisition regulations reflect this forecast-centric approach, and the upper half in figure 2 represents it graphically.
The forecast-centric approach can yield sophisticated capabilities by focusing DoD resources and leadership attention on a narrow set of initiatives, but puts the US military at a disadvantage if it is not already well ahead of adversaries. Predictions of future requirements are likely to be wrong or late-to-need against a peer competitor—for example, some PLA capabilities have emerged sooner than DoD analysts predicted. And by narrowly dedicating R&D efforts to satisfy ambitious long-term requirements, the forecast-centric approach reduces the US forces’ ability to shift to alternative technologies or concepts when forecasts prove incorrect.

Against a peer adversary, the US military will need to be less predictable and more adaptable. Instead of deriving advantage strictly through superior weapon, sensor, or platform technology, as the JCIDS or traditional acquisition processes suggest, the DoD will need to gain an edge through force employment and associated command, control, and communications (C3) capabilities. The lower portion of figure 2 depicts this decision-centric approach, which concedes potential gains in capability sophistication or specialization to afford commanders more options to organize, orchestrate, and sequence operations.

The US military is already adopting some decision-centric concepts and planning processes. New initiatives—including the Joint Warfighting Concept (JWC), Distributed Maritime Operations (DMO) concept, and Joint All-Domain Command and Control (JADC2)—rely on distribution; long-range effects chains connecting sensors, commanders, and weapons or electronic warfare platforms; and recomposable force packages to undermine PLA systems warfare and its “home-team” advantage in the western Pacific. By degrading an opponent’s sensing and sense-making while affording US forces more options for offensive actions, these initiatives aim to increase the US military’s lethality and resilience.

However, budget constraints will prevent the US military from becoming more distributed and recomposable by simply growing the existing, mostly crewed, force. To surmount this obstacle, the DoD will need to expand the proportion of the force comprising uncrewed systems while investing in the ability to identify and integrate new effects chains using AI-enabled C3 software. Rather than acting as extensions of crewed units,
Uncrewed systems in future effects chains will need to perform as independent elements of force packages or SoS. Whereas Cold War-era platform-based warfare relied on crewed aircraft, ships, or ground formations to contain most or all pieces of their own effects chains, an SoS approach assumes that different elements of the force will likely provide each link of an effects chain, from finding targets through engagement and assessment.\(^\text{17}\)

As figure 3 summarizes, adopting an SoS approach to force employment will allow the US military to fully exploit the characteristics of uncrewed systems. Because they are less expensive compared to crewed units, uncrewed systems can enable scaling of the force to increase distribution. The advent of a robust commercial robotics technology ecosystem further expands this opportunity by lowering costs and avoiding time-consuming R&D. With their scale and expendability, uncrewed systems can expand the variety of effects chains available to commanders and the dilemmas they impose on adversaries—provided forces treat them as independent players in an SoS. And because uncrewed systems can be more specialized and modular compared to crewed units that require multi-mission capability, forces can more easily plug them into effects chains to adapt an SoS to new missions or environments.

However, the need for uncrewed systems to contribute to adaptable effects chains as part of multiple SoS creates challenges for system development and integration. When developers design uncrewed systems as extensions of crewed units, such as in ISR operations, they can firmly define and pursue these systems’ requirements through conventional linear research and development. If an uncrewed system could participate in multiple different effects chains, its requirements would change depending on the other participants in each effects chain’s SoS. Crewed units overcome this challenge by establishing relatively ambitious requirements that capture the range of reasonable situations the unit could face. This approach results in capable and survivable units that are also too expensive to deploy at scale. Uncrewed systems will need a different approach for requirements and acquisition that assumes an SoS context. We explored this dynamic recently in a report focusing on the DoD’s Next Generation Air Dominance program.\(^\text{18}\)

The assumption of an SoS context is common in commercial technology development. Companies often develop a product to initially support a threshold “use case” or a combination of SoS configuration and application, such as a smartphone connecting through a cellular radio access network and the internet to access content on a website. Companies can develop other use cases over time as new SoS elements emerge or as they can realize new combinations of systems. The greater technology opportunity in commercial products therefore resides in integrating new SoS elements rather than in incrementally improving individual systems’ characteristics. For example, the streaming revolution that has dominated television and music delivery during the last decade resulted from the ability to integrate existing content providers, high-speed broadband internet backbones, 4GLTE or 5G networks, and mobile devices.

The DoD will need to similarly reframe its technological challenge as less about developing the next generation of superweapons and more about flexibly integrating existing and emerging capabilities to better address the threats and opportunities posed by peer competitors such as the PRC. With their ability to expand the forces’ scale and options, uncrewed systems are likely to be central to future US military SoS. The following chapters will therefore explore how the DoD could most effectively integrate uncrewed systems into US military forces. Chapter 2 will address the idea of autonomy and how limits on autonomy should shape DoD SoS development. Chapter 3 uses lessons from commercial robotics and industrial engineering to establish the concept of workflows and apply them to the mission threads associated with military effects chains. Chapter 4 describes how the DoD could identify and field uncrewed systems through experimentation and prototyping instead of separating R&D from procurement, as is the norm for crewed platforms. The report concludes with the study’s recommendations, which are summarized in chapter 5.
A popular characterization of uncrewed systems is that they are “autonomous,” but this is an overstatement because uncrewed systems depend on other force elements for essential support functions, from navigation to logistics. And as noted in chapter 1, part of the value of uncrewed systems is in their ability to increase the variety of effects chains available to commanders, suggesting that the DoD may most effectively employ them as part of an SoS. To clarify the relationship of uncrewed systems to other elements of the force, this study treats autonomy as the degree to which a system can be self-governing or operate without outside support with respect to execution of a task or function.

Under this definition, no unit is completely autonomous. Crewed warships and aircraft rely on offboard systems or forces for direction, information, sustainment, and repair, with the frequency of support depending on the mission. For example, a guided missile destroyer (DDG) attempting to defeat incoming cruise missiles may not be able to react in time to shoot down supersonic sea-skimming weapons unless it receives early warning from an outside sensor, like the radar on an E-2D aircraft. And even if the DDG can successfully shoot down all the missiles it faces, it will eventually need outside support to reload when it runs out of surface-to-air interceptors.

Photo: Sailors assigned to Commander, Task Force (CTF) 56 retrieve a Mark 18 Mod 2 underwater unmanned vehicle during training aboard a Mark VI patrol boat in the Arabian Gulf on May 5, 2021. (US Navy photo by Mass Communication Specialist 2nd Class William Collins III)
The limitations on uncrewed system autonomy are similar in kind to those of crewed platforms but often more severe in degree. The Navy’s planned medium unmanned surface vessel (MUSV) can operate without operator intervention for weeks at a time if it is conducting surveillance operations in an uncontested environment. However, as figure 4 shows, it will eventually need global positioning system (GPS) navigation updates, fuel, maintenance, and direction regarding search objectives or voyage planning. In more contested environments, the MUSV may need over-the-horizon (OTH) sensing to identify potential threats early and enable evasion.

Autonomy for a crewed or uncrewed platform is therefore never absolute. External intervention will always be necessary, with the amount and frequency of support or direction depending on the mission, the operating environment, and the sophistication of the unit in question. Reflecting this dynamic, almost all R&D efforts for crewed units have attempted to reduce their...
dependence on outside help by expanding weapons capacity, increasing sensor or countermeasure range or effectiveness, or improving reliability and endurance.

Instead of treating the limitations on autonomy as a problem that more expensive and sophisticated platforms and systems must solve, the DoD should embrace the inherent constraints on independent operation as an aspect of its shift toward adaptable effects chains and SoS constructs. Given that no unit is an island and that units always depend on other units for support or direction, the DoD should adopt development processes that pursue new capabilities with the assumption that they will be components of multiple SoS upon delivery. This creates, as noted in chapter 1, the challenge of defining acceptable requirements for a new system when its teammates and role can change from mission to mission.

This study will propose a process for defining acceptable performance of uncrewed systems by establishing reference use cases based on commanders’ contemporary operational problems. Starting from the reference case, the DoD could incorporate uncrewed systems into other mission threads and use cas-
es later. As figure 5 shows, this evolutionary approach reflects how the Navy has historically succeeded in uncrewed system development. For example, the Navy’s mainstay Mk-18 family of unmanned underwater vehicles (UUVs) evolved from Remus 100 and 600 vehicles developed by Hydroid for commercial applications. After more than a decade of refinements, Navy underwater construction and explosive ordnance disposal (EOD) teams use the Mk-18 Mod 1 and Mod 2 for everything from mine clearing to pier inspections.22

In addition to being evolutionary developments, nearly all the operational uncrewed systems shown in figure 5 perform a narrow set of functions and must work with other systems and human operators to complete a mission. For example, the Fleet-class USV grew out of the Common USV program, which the DoD designed to reflect characteristics of the Navy’s long-serving 11-meter rigid-hull inflatable boat (RHIB), which supports a variety of surveillance and transport operations.23 After the purpose-built uncrewed Remote Multi-Mission Vehicle (RMMV) failed to meet performance and reliability requirements, the Navy repurposed the Fleet USV to tow mine-hunting sonars or minesweeping gear as part of the littoral combat ship mine warfare mission package.24 The US Marines’ MQ-9A Reaper similarly evolved from the MQ-1 Predator and, although highly automated when performing sensing functions, requires operator direction to deploy weapons.25

The Navy has been less successful in developing uncrewed systems that attempt to perform multiple functions in contested environments—essentially replacing a crewed platform in that mission. When a vehicle’s functionality increases and the threat environment intensifies, a vehicle has to accommodate more decisions and actions, which generally reduces the time it can operate without external support. Figure 6 shows this relationship with vehicle sophistication on the vertical axis and duration of independent operation on the horizontal axis.

For example, currently available USVs such as the Saildrone Voyager, Ocean Aero Triton, or Liquid Robotics Shark can conduct ISR missions such as electronic intelligence or acoustic surveillance for months without significant external support by using wind, ocean currents, or solar power for energy and propulsion; passive radio frequency (RF) detection and computer vision to avoid other vessels; and satellite communications to offload data.26 In contrast, a small UUV (SUUV) decoy could operate for more than a day, but after a few hours it may need updated guidance regarding what, where, and when to decoy to avoid inadvertently attracting attention to US submarine operations.27

Weapons also reflect the relationship between complexity and scope or duration of mission. A Mk-48 torpedo has sufficient control logic to automatically seek and find a target without operator intervention, but to reacquire a lost target or attack a new target, the operator needs to direct the torpedo via its guidance wire.28 The newer long-range anti-ship missile (LRASM) has sufficient control logic to automatically find and engage a predefined target, such as a destroyer. If the DDG is already defeated or the LRASM detects a higher-priority target, such as an aircraft carrier (CV), the LRASM has sufficient control logic to adjust its own tasking and engage the new target.29 However, developers painstakingly create and test this specific automated behavior, and the LRASM would require outside direction to, for example, conduct a simultaneous time-of-arrival attack with a Tomahawk missile.

Some combinations of complexity and duration will be unachievable with available uncrewed vehicle technology, as figure 6 shows at the upper right. Systems that need to operate in this range, including several of the Navy’s high-profile uncrewed vehicle programs, drive R&D efforts that will take years to culminate. For example, a medium USV (MUSV) conducting counter-ISR operations in contested areas needs to sense and assess the environment, jam or decoy sensors based on mission plans, maneuver to improve ISR and counter-ISR efforts, and avoid other ships. Moreover, missions and the associated transit time could take several months, during which the MUSV...
must be able to mitigate or negate the impact of electrical and mechanical failures. The large number of decisions and actions that this use case requires drives MUSVs into what is currently an infeasible area for uncrewed system technology.

However, figure 6 also suggests an alternative approach for the Navy: field available uncrewed vehicles by adjusting the duration uncrewed systems need to operate without outside support or by integrating vehicles into an SoS to reduce their required complexity. In the example of the MUSV above, this could mean implementing an SoS for ISR and counter-ISR that employs MUSVs in less-contested areas and puts more numerous and expendable vehicles closer to the enemy. This use case is detailed in the next chapter.

Revising its requirements for uncrewed systems to make them achievable with today’s technology—as the US Congress directed in its FY2023 appropriations—would help the Navy speed its
fielding of uncrewed vehicles and associated SoS. But to enable this alignment, the Navy would need to narrow the variety of use cases and lower the associated requirements that it pursues for each of its uncrewed systems. This change would be a significant shift from the Navy’s current plans, which pursue uncrewed vehicles that can each support a variety of potential missions, like their crewed counterparts, which increases the vehicles’ complexity and the time and effort they require for development.

Developers sometimes use reference use cases in technology innovation to ensure a new system can deliver a minimum viable product for its most important application. Other use cases can come later. For example, the reference use case for the initial iPhone was to provide the functionality of the iPod MP3 player, access the web, and make telephone calls. Today, iPhones and other smartphones can support hundreds of different use cases. Similarly, the Navy could establish reference use cases for each category of vehicle to guide its uncrewed system development efforts. Reference use cases would address priority problems that operational commanders face today and rely on SoS and operator action where necessary to align vehicle requirements with available technology. As the uncrewed system and its surrounding SoS evolve, new use cases would become feasible and practical.

Although hardware will define the upper limit of how many variables a machine like an uncrewed vehicle seeks to control (e.g., how many control loops or similar control logic implementations are in its hardware and software), the use case dictates the number of necessary control loops. For example, driverless automobiles that operate outside known environments require a very large number of controlled variables, and with current technology they cannot operate for long periods without operator intervention, as recent accidents suggest. So for now driverless automobiles can only conduct short trips in environments like urban centers that are well mapped and where the vehicles can gather large amounts of data regarding local traffic patterns and behaviors.

Applying these insights to the Navy’s uncrewed vehicle efforts, figure 6 shows in green how the DoD could realign vehicle requirements to feasible reference use cases. While evolving the extra-large UUV (XLUUV) to eventually achieve sufficient reliability and endurance to conduct ASW patrols, US forces could employ it in the near term for shorter and less challenging mine deployment operations. Similarly, rather than using today’s MUSVs to independently conduct far-forward counter-ISR missions for months, the DoD could employ them for a few weeks at a time to tow sonar arrays as part of an ASW SoS in choke points outside adversary waters.

In defining its uncrewed system reference use cases, the Navy should learn from the automotive industry. In the last few years, at least ten companies attempting to develop universally applicable self-driving vehicles have failed or have been sold. Meanwhile, a robust industry has flourished around driver assistance technologies, including sensing, object recognition, automated steering, and braking. If self-driving cars eventually become viable from an economic and regulatory standpoint, it will be because these underlying technologies achieved scale in simpler use cases like hands-free highway driving. Like the automotive industry’s shift from driverless to driver-assist technology, the Navy should build reference use cases and requirements for uncrewed systems around the technology of today. As improved or new technologies emerge or new SoS configurations become possible, the Navy could evolve its use cases. To illustrate how the Navy could develop uncrewed system use cases and requirements, the next chapter addresses SoS conceptualization in terms of workflows, a common way of framing technology insertion in commercial settings.
The Navy’s current approach to fielding uncrewed systems largely mimics that for developing traditional crewed platforms. This is partly a function of the DoD’s budget process, which allocates funding to programs with formally established requirements, and partly due to acquisition regulations that mandate a deliberate process of R&D and testing prior to procurement. The US government created these processes to avoid mistakes in producing new crewed ships, aircraft, and vehicles, which are generally long-lived and multi-mission capable to provide the best return on their substantial development, procurement, and sustainment costs.

The other factor driving the Navy’s use of traditional acquisition processes for uncrewed systems is its pursuit of vehicles that can essentially replace crewed ships or aircraft in conducting select missions. The Navy envisions the LUSV, for example, as replacing a ship in long-range strike and surface warfare operations that rely on third-party targeting; it is pursuing the MUSV to conduct sensing and counter-sensing operations in contested waters in place of DDGs; and it characterizes the MQ-25 Stingray unmanned aerial system (UAS) as a replacement for the F/A-18 E/F Super Hornet in the aerial refueling mission. Although these concepts narrow the missions that the DoD demands of uncrewed systems and relieve them of the need to support and protect human operators, the LUSV, MUSV, and

DEVELOPING UNCREWED SYSTEMS AS PART OF WORKFLOWS OR MISSION THREADS

Photo: Sailors prepare an MQ-8C Fire Scout unmanned autonomous helicopter for takeoff on the flight deck of USS Milwaukee (LCS 5) in the Atlantic Ocean on December 15, 2021. (US Navy photo by Mass Communication Specialist 2nd Class Danielle Baker/Released)
MQ-25 require the same endurance and speed and nearly the same survivability as their crewed counterparts to accomplish their mission and justify the expense of building them. As a result, the Navy is developing them using the same acquisition process as for crewed platforms.

Building uncrewed systems to conduct select missions of crewed platforms in the same way as the crewed platform fails to exploit the potential of uncrewed systems, which lies in decomposing the functions associated with a mission and developing new effects chains or mission threads that accomplish the task in a more efficient, resilient, or scalable manner.

A useful analog is the industrial use of robotics. Businesses often characterize their processes as workflows rather than effects chains, but the underlying concept is similar: a sequence of industrial, administrative, or other processes through which a product or information passes from initiation to completion. A business can gain an advantage by establishing efficient workflows that reduce costs and improve responsiveness to market demands. Although a business does not face adversary action that seeks to degrade or defeat its workflows, customer expectations or priorities can change, supply chains can suffer disruption, and employment conditions can evolve. Like a military unit, a business can sustain an advantage or gain market share by adapting in the face of these changing circumstances.

Businesses can also use workflows to pursue disruptive change in the same way that a military attempts to implement a revolutionary new operational concept. Incrementally refining a workflow to improve efficiency can provide a marginal edge against a competitor, but fundamentally changing a process can yield a more enduring advantage. For example, computer companies like Dell and Compaq disrupted the computer manufacturing business during the 1990s by outsourcing all their components and becoming computer assemblers rather than building most of their own parts and integrating them using proprietary software like IBM or Apple. Starting in the late 2010s, Apple disrupted the assembly model by expanding its proprietary approach to include designing its own chips, which enabled Apple to synchronize its software and hardware and achieve dramatic performance improvements. Both changes gave the disruptors a multi-year advantage over their competitors.

Military disruptions reflect a similar dynamic. Facing Soviet numerical overmatch in conventional forces during the late Cold War, the US military pursued a new warfighting approach that would use technologies for precise surveillance and targeting, stealth aircraft, and guided weapons to find and attack Warsaw Pact forces in Central Europe. The efficiency of precision attacks would, in theory, enable US and NATO forces to stop larger enemy formations. The precision-strike approach is now itself ripe for disruption as its underlying technologies proliferate and US adversaries more widely understand its operational concepts.

Incorporating Robotics into Adaptable Workflows

Manufacturing and logistics companies began employing robots widely in the 1990s to gain a competitive advantage by improving the speed, repeatability, or cost of their processes. Figure 7 shows the example of a regional hub for a package delivery company that receives packages, sorts them, and routes them to the intended recipients as efficiently as possible. Although the company can routinize the hub’s workflow, it will need to accommodate changing volumes, sizes, and types of packages; respond to seasonal variability in demand; and adapt to the timing requirements of customers and suppliers.

The workflow of figure 7 would initially incorporate human operators to conduct most tasks. Companies automated some tasks using available technologies by focusing on elements they could easily mechanize, such as conveying and scanning similarly sized packages to or from trucks or determining routes for drivers to follow. However, the need to compete on price and speed spurred further efforts to improve workflows’
throughput and effectiveness with the same number of employees or fewer. As a result, mobile robotics are beginning to automate more workflow steps in these distribution hubs, such as moving boxes from inbound to outbound sides of the warehouse.

An initiative to expand the use of robotics in the workflow of figure 7 can take one of two paths, as figure 8 shows. The left side of figure 8 depicts the option of replacing workers with machines that mimic the roles and actions of humans. If successful, this top-down approach would develop robots that could replace workers in any task they currently conduct. In addition to enabling the incorporation of robots into existing workflows, this approach would simplify scaling of the hub’s operations. However, efforts to develop versatile human-like robots have failed to produce mature, useful systems.46 Although researchers can integrate sufficiently capable hardware, albeit at a high cost, software that enables such systems to operate robustly has been elusive. The Navy is arguably taking this approach with its MUSV and LUSV programs, which require the same endurance, speed, and ability to avoid or defeat threats as a crewed combatant ship.
The right side of figure 8 depicts an alternative path to introducing robots into the warehouse’s workflow. In this bottom-up approach, existing robots with limited functionality, range, endurance, and sophistication perform simple tasks, and the company organizes the workflow around their capabilities. While the model on the left requires a robot to move, think, and pick up objects like a human, the model on the right demands only that robots perform tasks they can already do, like moving from one location to another based on direction from a central routing management computer. In the model on the right, humans continue to conduct functions that are easy for them but are hard to enable a robot to do, like recognizing and picking up various-sized objects and placing them in a specific location. This is a model of human-machine synergy built around information-technology-enabled workflows.

The bottom-up model of automation adaption not only respects the respective technical and physical constraints of...
humans, robotics, and other technologies but also enables more adaptable workflows. The warehouse on the left side of figure 8 can add robots to increase production, but costs will increase linearly with productivity. In contrast, the warehouse on the right could scale by deploying additional inexpensive robotic carts and software to make each human worker more efficient; costs in that case would increase less than linearly with productivity. As new robotics or automation software becomes available, the company can decompose and reallocate tasks to incorporate new systems and technology. This allows businesses to view automation not as a one-time efficiency improvement but as a tool to achieve continual, year-over-year advances in not only efficiency but also other metrics like resilience and adaptability.46 However, realizing the sustained benefits of this approach requires the ability to integrate never-ending combinations of robots and information technologies into ongoing operations.

Applying the Bottom-Up Model to Military Use Cases

The Navy should apply the workflow approach to its development of teams that best exploit the characteristics of available uncrewed systems and existing crewed platforms. As a largely expeditionary force, the US military will continue to depend on crewed ships, vehicles, and aircraft to maintain operators on station, protect noncombatants and support nodes, and carry and sustain smaller uncrewed systems. However, as previous studies and the discussion below suggest, uncrewed systems could contribute to a growing range of militarily relevant functions in concert with crewed platforms.47

To determine the best ways to employ uncrewed systems, the DoD should decompose military missions into workflows or mission threads like that of the distribution warehouse in figure 7. A mission thread describes all the tasks an operation requires, such as in the mine-clearing example of figure 9. Previous generations of mine-clearance systems were crewed, multi-mission platforms such as the CH-53M helicopter or the Avenger-class mine countermeasures (MCM) ship. These platforms would drive over or through a suspected minefield and use acoustic or magnetic detectors, respectively, to find mines. After detecting mines, the platforms would note their locations, and either the MCM or the MH-53M would return with sweep gear to collect them—likely detonating some safely in the process. Alternatively, MCM operators could destroy or deactivate mines using divers or the EX116 mod 0 remotely operated vehicle.

Starting in the mid-2000s, the Navy began a program for mine-clearing that would rely predominantly on uncrewed systems deployed by the new littoral combat ships (LCS). The associated SoS was pursued using a forecast-centric systems engineering approach, which established requirements based on a projected set of future procedures and tactics. Due to challenges in developing the needed technologies—not unlike those facing the commercial robots on the left side of figure 8—the Navy shifted to a bottom-up approach using existing uncrewed systems and adapting their planned mine-clearing workflow to accommodate the available technology.48

The resulting mine-clearing mission thread is depicted in figure 9. A large-capacity host vessel, such as an expeditionary staging base (ESB) or LCS, carries UUVs, unmanned aerial vehicles (UAVs), and USVs to an area adjacent to the suspected minefield. Using small boats, davits, or ramps, the ESB deploys UUVs or USV-towed sonars to search the ocean bottom for potential mines while UAVs scan the area for floating mines and provide communication relays for uncrewed systems that may travel over-the-horizon from the ESB. Both types of uncrewed systems can use algorithmic target recognition to differentiate mine-like objects from other material in the water, such as infrastructure or debris. When UUVs and UAVs discover mine-like objects, they will report them to the ESB or LCS and enable operators to plan clearing operations. The host vessel will then send out robot mine detonators, divers who can deactivate mines, or USVs towing mechanical or magnetic sweep gear to collect or detonate mines.49
The decomposition of the mine-clearance mission into discrete functions improves the workflow’s adaptability and resilience by providing multiple paths to mission completion as opposed to each mission having to proceed through the choke point of an MCM vessel or helicopter. For example, self-propelled UUVs like the Mk-18 or sonars like the AQS-20 towed by USVs could detect bottom mines. UAS or helicopters carrying the Airborne Laser Mine-Detection System (ALMDS) could detect floating or near-surface mines, and multiple uncrewed or human-centered methods, from sweeping to detonation, could neutralize mines. The mission thread of figure 9 is also more scalable compared to the current approach because it no longer depends on a small fleet of crewed helicopters or ships whose costs and personnel requirements grow linearly with the number of platforms. Although the Navy will continue to need MCM specialists, uncrewed MCM systems could be placed in storage with limited maintenance or used for other missions, like oceanographic surveys or ISR, when they are not being used for mine-clearing. And as in the warehouse example above, when naval forces need to expand the scope of mine-clearing, they can deploy more uncrewed systems without substantially increasing the number of MCM personnel because each operator can manage multiple vehicles and additional operators can undergo training on simulators.

Using Bottom-up Workflows to Accelerate Uncrewed System Fielding

The example above describes a mission thread that the Navy adopted out of necessity when its top-down approach failed to yield a workable SoS. The decade-plus process of eventually arriving at the SoS shown in figure 9 could have been avoided if the Navy had followed a bottom-up model of SoS development from the start. As noted above, the Navy’s MUSV program is pursuing ambitious requirements for reliability and autonomy to enable it to support counter-ISR in highly contested areas. The example below describes how the bottom-up model could be applied to counter-ISR operations and reveal mission threads that apply available uncrewed vehicle and mission system technologies.
The PLA fields an extensive network of anti-ship cruise and ballistic missiles based on Chinese territory and maritime features that China has built in the South China Sea and carried by PLA ships and aircraft. These precision weapons depend on commercial and military surveillance networks in every domain, from geostationary-equatorial orbit and low-earth orbit satellites to ground-based, shipboard, and airborne radars and passive RF sensors. Together, this reconnaissance-strike complex poses the most significant threat to US naval forces operating in the western Pacific and South China Sea.

Historically, US naval forces facing a ground-based threat like those that China’s anti-ship missiles pose would remain out of range of as many adversary weapons as possible and launch standoff attacks that degrade the adversary’s capability until naval forces could approach more closely. The key operational problem today is that the range and density of PLA sensors and weapons prevent US naval forces from launching any meaningful strikes into potential conflict zones, like the Taiwan Strait, from outside the reach of PLA ground-based missiles.

The mission thread would address this problem by employing EW systems and uncrewed vehicles to enable a surface action group (SAG) to penetrate a contested area covered by PLA airborne, satellite, and ground-based radars and passive signals intelligence (SIGINT) sensors so that the SAG can attack PLAN forces in the Taiwan Strait. Figure 10 depicts the workflow or mission thread.

The PLA sensors with the widest area coverage are SIGINT satellites. To defeat these sensors, US surface ships would operate using emissions control (EMCON) in which their radios and radars are deenergized. In concert, the mission thread would use USVs

Figure 10: Workflow for Enabling a SAG to Penetrate a Contested Area
or UUVs with RF emitters that mimic signals that DDGs generate to act as decoys. To reduce the acuity of SIGINT sensors, USVs, perhaps with the aid of UAVs equipped with EW systems, would emit RF noise between the SAG or the decoys and the enemy sensors. A common mistake in decoy operations is that the decoy is easier to detect than the real unit, allowing the enemy to differentiate true from false targets. By masking both real and decoy ships, the mission thread would complicate differentiating between them.51

Wide-area active sensors, such as the PLA’s high-frequency over-the-horizon radar (OTH-R) and synthetic aperture radar (SAR) satellites, represent the next most significant detection threat to the SAG. The mission thread would address these threats by using jammers on board USVs or UAVs. Because SAR and OTH-R radars operate in different frequency ranges and jammers would need to be in different positions to be effective, separate vehicles would be necessary for each.

If US forces do not coordinate decoy and jamming operations well across geographic areas, enemy forces could determine the locations of US forces by comparing real-time information from multiple sensors. To reduce this potential, the mission thread could use UUVs or small USVs that could position themselves near their targets to jam wireless communication links between mobile enemy platforms, relocatable sensors and weapons, and command centers.

The commander of the SAG would manage deception operations using passive sensors to avoid counter-detection. Relying on passive sensors would also allow the commander to use

Figure 11: Mission Threads Associated with New Counter-ISR SoS

Source: Authors.
planning tools such as Real-Time Spectrum Operations (RTSO) to build an estimate of what the SAG looks like to PLA SIGINT systems and to orchestrate decoy and deception actions to maximize their effectiveness. Figure 11 depicts the mission threads with the greatest executability and effectiveness as evaluated through physical and virtual experimentation.

Like the MCM example above, the counter-ISR mission thread includes multiple paths for achieving intended effects. As new capabilities become available or evolve, the mission thread could expand to include new paths that improve the mission thread’s adaptability and resilience.

Shifting from Human to Machine Communication

The versatility of uncrewed systems, like that shown in figure 11, emerges in part from their ability to participate in open architectures and to use modular, digital payloads such as radios, radars, EW jammers, or weapons. Crewed platforms also often use open architecture constructs, but the need to justify their expense by performing multiple functions precludes them from carrying only one or two mission systems. As the number of radios, sensors, and countermeasures increases on a crewed ship or aircraft, space and weight constraints tend to require greater degrees of integration, limiting the ability of the platform to easily swap out mission systems.

Rather than being highly integrated as in a crewed platform, uncrewed systems can decouple sensors and radios necessary for vehicle operation from those for mission threads because they need less self-protection and can have limited functionality. In addition to allowing easier exchange of radios, sensors, or countermeasures, the separation of uncrewed vehicles from the mission systems they carry enables different levels of external intervention or autonomy for the vehicle and its sensors or weapons. For example, the MQ-4C Triton UAV is highly automated and requires minimal planning and direction to safely fly a route. In contrast, offboard human operators or automated programs often control MQ-4C mission systems, such as electro-optical and infrared (EO/IR) cameras or passive RF sensors, in real time to manage the amount of data processing and focus sensors on items of interest.

In some use cases, vehicles may interact with their mission systems to gain operational benefits. Early instances of automation in platforms could only reduce how often humans had to perform less sophisticated functions, such as moving vehicle control surfaces, orienting a sensor toward an expected target, or setting radio frequency and pulse characteristics in accordance with communication plans. Current levels of automation are enabling platforms to manage their own route planning and movement, recognize targets and responsively change mission plans, and dynamically configure data and networks to best support intended missions. Sophisticated automations like these are often improved by integrating mission systems with vehicle control systems. In other cases, the need for lower-cost and more expendable uncrewed systems will demand decoupling mission systems from vehicles to reduce complexity.

Realizing the benefits of crewed-uncrewed mission threads will depend on effectively integrating multiple mission systems with their host platform as well as with those on other vehicles. The DoD has traditionally treated integration as an activity it conducts almost exclusively during initial system development. When force packages are assembled in theater, DoD acquisition processes expect them to coordinate through procedure, much like they did during the twentieth century. However, as the discussion above suggests, the achievement of scale, adaptability, and resilience in future operations will depend on the ability to knit together new mission threads comprising a growing proportion of uncrewed systems. This approach essentially exchanges the internal complexity of crewed multi-mission platforms that are integrated through human communication for the external complexity of crewed-uncrewed teams that integrate using machine-to-machine communication. The next chapter describes how the DoD could implement this process of mission integration.
Addressing operational needs by combining existing crewed platforms and available uncrewed systems into mission threads is nearly the opposite of the US military’s current approach to fielding new capabilities. Today, the DoD often uses a top-down process of systems engineering to identify the requirements to complete a mission based on projected future procedures or tactics. Analysts map gaps in the force’s ability to execute the mission to potential new platforms or mission systems that acquisition professionals then pursue. This is the approach embodied in the systems engineering "V"—starting with an identified need, decomposing the need into a series of engineering activities, maturing and testing the results of each activity, and then integrating them into a whole product. The result is often a workflow or mission thread built around a major platform. Not only does the DoD apply this systems engineering approach to developing weapons, but it has also recently explored the application of systems engineering to developing workflows themselves in a process known as mission engineering. Using top-down systems engineering to develop a mission thread could arguably be an appropriate method of SoS development if many of the necessary systems do not yet exist and if there is sufficient time to develop, integrate, and field them. However, neither of those conditions exists today. A wide vari-
A bottom-up approach to mission integration would also be better suited for developing SoS that incorporate a growing proportion of uncrewed systems. Mature uncrewed systems in all domains are available but generally lack the combination of speed, functionality, range, and payload that is common in crewed platforms. A top-down system engineering methodology would inevitably create requirements that do not align with existing uncrewed systems’ specifications and would result in either a protracted R&D project to produce the needed systems or an iterative process, like the Navy’s Requirements Evaluation Teams (RET), that refine requirements to align with a program’s technological or fiscal constraints.

Figure 12: The Viscous Cycle Associated with Pursuing Uncrewed Systems through Mission Engineering

Replacing crewed platforms raises requirements for speed, endurance, sense/avoid.
- LUSV for DDG in missile launch
- MUSV for DDG in ES/EA
- MQ-25 for F/A-18 E/F in tanking
- MQ-4C for EP-3/P-8 in ISR

Appropriate in some cases
- MQ-25 solves a significant operational problem and no existing solutions.

Vision-Reality Mismatch
Navy under pressure: not enough hulls to meet fleet/CCMD demands. Navy pursues UxVs that can replace crewed ships.

Industry hype attempts to build support for the integrated replacements for crewed platforms.

Don’t Invest
Cut or limit appropriations related to operationalization or procurement of uncrewed systems based on lack of evidence.

Insufficient funding or effort devoted to operational concept development and experimentation, and workflow redesign that would enable fielding of simple robust components.

Not Mature
Slower R&D of Navy’s purpose-built integrated replacements for crewed platforms.

UxS cannot meet demands; Decay of congressional trust.

High

Low

System Robustness

Narrow
Use Case Generality

Broad

"Model A"

Source: Authors.
The Navy’s recent uncrewed system development efforts reflect a systems engineering—rather than a mission integration—approach. Like the warehouse distribution company on the left side of figure 8 that pursued highly sophisticated robots to mimic human functionality, the Navy decomposed missions that crewed platforms conducted and identified the requirements of an uncrewed system that would replace the crewed platform in that mission thread. As the left side of figure 12 shows, the Navy intended for its LUSV, MUSV, MQ-25, MQ-4C, and XLUUV programs to create an uncrewed system able to perform functions of a crewed platform in existing mission threads and to fulfill similar requirements.61

The Navy’s attempt to plug uncrewed systems into mission threads built around crewed platforms gives rise to a vicious cycle that ultimately undermines the Navy’s goal of a hybrid crewed-uncrewed fleet.62 As the right side of figure 12 summarizes, the protracted R&D process and failure to quickly deliver on the ambitious requirements for uncrewed surface programs like MUSV and LUSV eroded congressional trust, resulting in funding reductions that further delayed system development.63 More important, reductions in funding also precluded the Navy from conducting the experimentation or modeling and simulation (M&S) that could have enabled it to shift to a bottom-up approach of building workflows or mission threads out of existing systems.

The Navy’s history with uncrewed air and undersea programs highlights that mission integration requires both a reliance on existing systems and a willingness to revise or create new workflows to accommodate their current characteristics. For example, the MQ-4C Triton, based on the Air Force MQ-4A Global Hawk, required extensive modifications to operate in a maritime environment and to support Navy ISR missions similar to those EP-3 Ares or P-8A Poseidon aircraft performed. The cost of these changes and the growing availability of space-based capabilities led the Navy to reduce its planned number of MQ-4Cs by two-thirds.64 The Orca XLUUV, based on Boeing’s Echo Voyager prototype, experienced schedule delays in production and challenges with in-water testing as its builder attempted to meet requirements for sophisticated long-endurance missions like those that submarines perform. The Navy is now descoping its mission set to initially focus on minelaying.65 And although the Navy’s new MQ-25 Stingray uncrewed aerial refueling tanker is based on a Boeing prototype, Boeing initially developed that aircraft in response to Navy requests in the early 2010s for an unmanned carrier launched surveillance and strike (UCLASS) aircraft that could conduct long-range attacks.66 Because the Navy viewed technology at that time as unable to support this sophisticated mission at an affordable cost, it descoped the aircraft’s role to refueling over a decade of deliberation.67

Like in the package distribution center of figure 7, the Navy should adopt a process that composes extant systems, or slightly modified versions of them, into viable workflows that evolve as new technology emerges. Figure 13 summarizes the technical aspects of this approach. Operators would start the process by using live, virtual, and constructive (LVC) environments to develop concepts and mission threads using uncrewed vehicles, mission systems, and crewed platforms that are likely to be available in the relevant time frame. The Navy would assess promising SoS using modeling and simulation to evaluate their performance under likely operating conditions, and then implement the most viable workflows and SoS in experiments to gauge their executability.

The multi-year process of contracting and engineering necessary to modify legacy operational flight plan software on an aircraft like the F-35 might not be justifiable for an experiment with an uncertain outcome. Therefore, experiments might rely on digital surrogates, sidecar computing, and workarounds that enable interoperability without modifying underlying software to show whether a particular workflow is useful and executable without the time and expense of conventional software or hardware modifications that are typical for fielded military SoS. For
example, developers could temporarily modify the software of a developmental variant of a multi-function RF system to test new behaviors or waveforms necessary in the new use case without making class-wide changes to those systems. The Navy is pursuing experiments like this already with US Central Command’s Task Force 59 in the Persian Gulf and with the US Third Fleet’s series of integrated battle problems.68

The Navy would need to properly integrate promising SoS from experiments before it could field them in prototype form to support further experiments or real-world operations. The US military has long pursued approaches to integrate disparate systems into force packages, kill chains, and now mission threads. Until the twenty-first century, it mainly accomplished integration by aligning doctrine and procedures because humans operated nearly all equipment. Today, automation and machine-to-machine communication between vehicles, platforms, and systems reduce the need for human operators to act as intermediaries. In most mission threads, increasing operator involvement is more likely to reduce performance than to improve it.

Digital integration will not be easy. Different engineering teams designed most weapons and mission systems in isolation, with
different computers, interconnects, and software build chains, rendering them incompatible and resistant to easy updates. The Navy would likely need to replace off-the-shelf communications equipment and encryption in commercial or demonstration systems with those used by US forces, although it could allow commercial radios to remain as a backup. Commercial computer hardware and software and sensors may be acceptable in their current form, depending on the mission thread’s processes and SoS composition. And, most important, The Navy would need to incorporate the SoS elements into a software environment that it uses for C2 and that enables data transfer within and outside the SoS.

Structuring for Mission Integration

Mission integration requires organizations and processes that understand commanders’ operational problems, survey available technologies, evaluate SoS through simulation and experimentation, and engineer C3 software to integrate systems. And after the DoD successfully identifies a new SoS, it will need to promptly acquire the elements not already extant in the force at

Figure 14: A Functional View of the Mission Integration Process

FUNCTION 1
Define Key Operational Problems (KOPs)
Suggest multiple candidate courses of action and systems-of-systems solutions to operational problem

FUNCTION 2
Execute experimentation around KOP and systems-of-system solution recommendations
Oversee prototyping of early tactics, C2/data/UI/comms elements for systems of systems

FUNCTION 3
Acquisition or leasing of building blocks—generally simpler, fewer-functional uncrewed vehicles and mission systems

FUNCTION 4
Initial and ongoing support for the digital integration of SoS components

FUNCTION 5
Resourcing and requirements validation

FUNCTION 6
Training of Personnel
Continued refinement of employment and tactics
Feedback to functions 4 and 3
Use in operations

Source: Authors. NIF=Naval Integration Framework; CCMD=Combatant Commander.
a sufficient scale to be operationally relevant. Parts of the DoD, such as the Navy’s efforts through its Unmanned Task Force, arguably conduct all these activities today, but the processes are generally not well orchestrated or synchronized due to a lack of dedicated funding and clear lines of authority and responsibility.

Figure 14 depicts the mission integration process in terms of six main functions, which will be described below in the context of the Navy. The process starts with Function 1, which identifies a key operational problem facing a commander such as commander, US Pacific Fleet (COMPACFLT), and formulates some initial mission threads and associated SoS that could address the problem. Function 2 would assess the proposed mission thread and SoS from Function 1 as well as other potential solutions using M&S and LVC capabilities. Concept development organizations like the Navy’s Surface and Mine Warfare Development Command (SMWDC) would use field or fleet experimentation to evaluate the most promising candidate mission threads and SoS. An essential element of Function 2 is understanding the available technologies, with support from the efforts of Function 3, which obtains systems and vehicles to support experiments and prototype implementations. In recent DoD experiments, the experimenting organization largely performs Function 3. However, because experimentation organizations are not acquisition authorities, experiments and prototype implementations rarely result in a prototype transitioning to become a formal DoD acquisition program. Under a mission integration approach, acquisition professionals would support Function 3 in a way that enables elements of a successful SoS to proceed promptly into acquisition.

The Central Role of Software in Mission Integration

Software is the glue that binds together human operators, mission systems, and uncrewed vehicles in developing and executing evolving tactics. Software controls a majority of the functions that uncrewed systems and the payloads they carry perform—including sensing, communications, data fusion, and decision support. Creating a mission thread means getting the software from disparate mission systems to interoperate. Achieving adaptability and resilience necessitates the development of approaches that can integrate heterogeneous SoS elements seamlessly without resulting in a one-off solution that the DoD cannot modify to support other SoS configurations or tactics. The DoD’s future success in employing uncrewed systems and SoS generally therefore hinges on its ability to integrate, develop, and acquire software in a manner that is adaptable, evolutionary, and responsive to the rapid pace of change.

As with hardware, DoD software acquisition has traditionally focused on top-down systems engineering rather than on iterative development, despite software’s ability to be modified at low or no expense. Long delays, cost overruns, and ineffective delivery of capabilities have resulted due, in part, to this outdated approach. To compete effectively in the future, the DoD has to adopt modern practices that develop software while incorporating security features and feedback from operators, or DevSecOps. A recent Hudson Institute report focusing on program managers and other acquisition professionals provided a template for software acquisition practices called Acquisition Competency Targets for Software (ACTS). These include evaluating existing software factories, recruiting top software talent, focusing on service levels, and defining zero-trust outcomes. Treating software as a vital component and integrating it effectively into mission systems will be the key to the Navy’s success in the future. The structure of Function 4, detailed below, outlines the specific infrastructure, tools, and processes appropriate for mission integration.⁶⁹
As described above, the DoD would need to digitally integrate mission threads and SoS that succeeded in experiments to create a prototype SoS that could support more robust experiments or real-world operations. Organizations such as the Navy’s Information Warfare Command (NAVWAR) would digitally integrate the various mission systems and vehicles into a C3 architecture for the new SoS under Function 4, which is the central activity in mission integration (see callout box). Function 5 allocates funding for mission integration activities to ensure a coherent and sustained effort at SoS development; because funding is normally associated with requirements, Function 5 would also include validation that a prototype SoS emerging from successful experiments addresses commanders’ operational problems. In conjunction with Function 5, Function 6 would consist of commanders assessing a prototype SoS in the field and either validating its requirements or proposing refinements.

Successful mission integration will depend on iteratively evolving mission threads and SoS in response to new technologies and operator feedback. Therefore, although figure 14 implies Functions 1 through 6 happen in series, they would actually occur in parallel and interactively. For example, Function 1 of defining operational problems and initial solutions depends on uncrewed vehicles and mission systems that the DoD identifies and obtains as part of Function 3. Function 6 will provide insights back to Functions 2 and 3 regarding useful operational concepts and systems. The process of concept development in Function 2 can be informed by efforts at digital integration in Function 4, which will highlight SoS combinations that are harder or easier to create. And conversely, a more detailed digital model-based analysis in Function 2 can make digital integration easier to perform in Function 4.

Although the Navy already conducts Functions 1–4 and 6 in some form, it lacks a way of orchestrating these activities to promptly move a solution from idea to implementation and to establish a feedback loop that evolves mission threads and SoS over time. For instance, the Navy Unmanned Task Force (UTF) supports commanders such as COMPACFLT and commander, Naval Forces Europe (COMNAVEUR) in defining operational problems under Function 1 and evaluates potential mission threads and SoS through a series of sprints as part of Function 2. A variety of organizations find and obtain vehicles and systems for experimentation and eventual prototype SoS, such as the Defense Innovation Unit (DIU) in support of Task Force 59. Multiple organizations also perform Function 4, with commercial software companies integrating systems in support of Task Force 59 and NAVWAR conducting digital integration of crewed platforms in carrier strike groups under the Navy’s Project Overmatch.

However, the DoD’s current programming and budgeting processes do not reflect Function 5, which may be the most significant change necessary to enable effective SoS development efforts. The DoD provides funding for Functions 1–4 and 6 through a set of budget program elements (PE) that span multiple resource sponsors and appropriations across procurement; operations and maintenance (O&M); military personnel; and research and development, test, and evaluation (RDTE). Computer-based tools can make the process of organizing and managing SoS development resources relatively straightforward, but in many cases the source of funding for an activity may not align with the resource sponsor or organization that benefits from the result, requiring compromises to ensure forces field some SoS in a timely manner. For example, funding for buying or building UUVs in Function 3 generally comes from the chief of naval operations staff (OPNAV) undersea warfare directorate (OPNAV N97), which also funds mission integration and experimentation activities at Navy Undersea Warfare Centers (NUWC). However, a concept that uses UUVs as part of an SoS for ASW may primarily support the surface warfare community. Preventing these misalignments from undermining SoS capability development efforts may require a dedicated sponsor to fund some functions in Figure 14.
Implications for Organizations and Processes
The Navy could improve the timeliness and relevance of its SoS by creating a coherent process of mission integration and by placing a new Innovation Office in charge of it. Instead of having an ad hoc collection of organizations conduct Functions 1–6 from figure 14, the Department of the Navy (DoN) should assign responsibilities for these functions to specific offices, with appropriate resources and authorities. And although this report focuses on improving the Navy’s ability to exploit uncrewed systems, arguably almost any future SoS will incorporate uncrewed elements. The emergence of uncrewed systems is merely revealing long-standing limitations of the Navy and other services in integrating new SoS in support of novel mission threads. Figure 15 summarizes one approach for aligning Functions 1–6 with new and existing service organizations.

Figure 15: Proposed Organizational Construct for Developing SoS with Uncrewed Elements
Function 1: Defining Operational Problems

Commanders such as COMPACFLT, COMNAVEUR, and commander, Naval Forces Central Command (COMNAVCENT) would lead Function 1 by defining key operational problems and developing initial mission threads and SoS, much like they do today. These commanders and their staffs are familiar with the challenges associated with their areas of responsibility (AOR) and are responsible for building plans to support combatant commander and national objectives. They also have the analytic capacity to provide at least initial assessments of the mission threads and SoS that they could use to address key operational problems.

The systems engineering approach and DoD requirements processes assert that today’s commanders are not in a good position to define problems because solution development is necessarily future-focused. This argument fails on multiple counts. First, challenges that the PRC and Russia pose are contemporary issues, as demonstrated by the war in Ukraine and DoD officials’ statements regarding the potential for Chinese aggression in this decade. Second, the availability of US and allied military and commercial technology suggests opportunities exist to improve US forces in the near term through the adaptation of current capabilities and more effective integration—a conclusion borne out by Ukrainian forces’ success against Russian invaders. Third, building adaptable software-enabled SoS (see callout box above) will enable the integration of new systems as they become available. And last, the highly sophisticated capabilities demanding dedicated long-term defense R&D efforts would continue on a separate path from that of near-term mission integration.

Function 2: Developing Mission Thread and SoS Solutions

Because operational commanders will have limited visibility of the technologies available to support potential solutions, the Innovation Office would assist them by continuously surveying advancements in government, defense industry, and commercial uncrewed vehicles, mission systems, and software. The Innovation Office would consult the broader DoD R&D enterprise to inform its surveys, including research organizations like the Defense Advanced Research Projects Agency (DARPA), the Office of Naval Research (ONR), and organizations charged with harnessing commercial technologies, such as NavalX and the Defense Innovation Unit. The Innovation Office would refine proposed SoS and mission threads from operational commanders using M&S and LVC capabilities in a series of development sprints like those the Navy Unmanned Task Force performs today. In doing so, the Innovation Office would be able to leverage the growing variety of LVC capabilities in the DoD. For example, the Navy operates the DoD’s largest LVC simulation environment in the Navy Continuous Training Environment (NCTE). And in the air domain, the Navy–Air Force Joint Simulation Environment (JSE) is progressing from a networked F-35 trainer to an environment that allows for LVC of complex new systems-of-systems configurations with demanding security needs.

The Innovation Office would use experimentation to evaluate promising SoS and mission threads developed during sprints. It would initiate and manage experiments through concept and tactics development organizations such SMWDC, Navy Air Warfare Center Aircraft Division (NAWCAD), or Undersea Warfare Development Command (UWDC). To ensure prioritization of experimentation addressing commanders’ operational problems, the Innovation Office would provide funding to support organizations.

Function 3: Provisioning and the DevOps PM

As part of Function 3, a growing variety of government and commercial providers should supply the vehicles and systems for experiments, given the DoD’s desire to expand the options available to commanders and to take advantage of the capacity and lower cost possible with commercial systems. Today, executing Function 3 requires experimentation organizations to coordinate between a complex array of contracting offices and funding sources. In the proposed model of figure 15, the DoD would establish a development and operations program manager (DevOps PM) in each program executive office (PEO)
overseeing uncrewed vehicles to support experimentation by arranging for vehicles, systems, and platforms to be made available.75

Although acquisition program managers are not normally involved in experimentation, creating DevOps PMs yields benefits across multiple functions in the mission integration process. The DevOps PM would improve the performance of Functions 2 and 3 by ensuring the ability to fund or contract experimentation efforts if the experimentation organization lacks the organic capacity to do so. For example, the DevOps PM could transmit funds to readiness squadrons for crewed ships to participate in an event; contract a commercial uncrewed vehicle manufacturer to provide vehicles and operators under a contractor-owned, contractor-operated (CO-CO) model; pay for a warfare center to provide range time; or contract with a commercial software developer to support the temporary C3 integration necessary during the experiment. In some cases, the experimentation organization has established mechanisms and relationships for Function 3, in which case the DevOps PM may only need to ensure the transmission of funding to the experimentation organization to resource those efforts.

A DevOps PM would also help address the challenge of technology transition as part of Function 5 by creating an intersection between experimentation and acquisition. The DoD could indefinitely use CO-CO or “as a service” models for missions like surveillance. However, most tasks that uncrewed systems would perform in mission threads that address commanders’ operational problems will be difficult to define in a firm, standalone requirement for a service-level agreement (SLA).76 High-priority operational problems are by definition challenging for the current force to address because of risks to crewed platforms or the dynamism of the operation. Addressing these situations will likely demand that operators be able to change how they employ uncrewed systems and their associated SoS as the mission proceeds, including by sacrificing uncrewed systems to accomplish the task. CO-CO or service contracting models do not lend themselves to this level of flexibility, suggesting that the systems should be government-owned.

Promising commercial or developmental systems emerging from experimentation rarely transition directly to become government-owned systems because experiments do not incorporate appropriate competition and transparency. Because it is an acquisition office working under a PEO, the DevOps PM could help enable a faster transition from CO-CO to government-owned by ensuring internal and external teams conduct the process of competition, experimentation, and evaluation in ways that are defensible and appropriate under acquisition models such as the Middle Tier of Acquisition (MTA).77

Function 4: Digital Integration

The role of Function 4 is to provide the environments, infrastructure, tools, and processes that enable digital integration of the software elements necessary to complete an SoS mission thread. New technologies, concepts, and ideas will likely emerge faster than consensus software standards can evolve to accommodate. Therefore, in contrast to prime contractor models common during the twentieth century, in which a single vendor provided the hardware and software for a new system, software for the next generation of mission threads will need to come from a variety of developers within and outside the DoD and span a diverse set of hardware and security environments from mission systems to cloud computing servers. To enable this kind of agile software development, the proposed construct for Function 4 reflects approaches from the commercial sector, which treat the overall software environment as a separate product from the platforms and systems that interact with it. This will help lower barriers to entry for developers that hope to introduce new software innovations.

For example, the Apple iOS operating system is a distinct project from the iPhone and from applications in the Apple AppStore. Apple exposes the interfaces that applications need to use to operate within iOS and provides developmental toolkits for ven-
dors to use in creating their applications. Companies proposing applications and peripherals for the iPhone need to prove that they can effectively and securely integrate with iOS before they gain approval for use.\textsuperscript{78} For the government, the integration challenge is more daunting. Whereas Apple has only a dozen iPhone versions using iOS, the US military has tens of thousands of existing mission systems and crewed platforms it may need to integrate with hundreds of emerging uncrewed systems, creating a web of data engineering, radio interoperability, and security issues. The DoD’s JADC2 strategy wrongly assumed that all these legacy and new systems would eventually need to integrate with one another. In contrast, the bottom-up model of Function 4 would instead integrate only those SoS that demonstrate value in solving near-term operational problems.

Figure 16 shows how the proposed construct would implement digital integration, which institutionalizes elements of the Navy’s emerging model for uncrewed system software development. Overall, in this construct a dedicated software ecosystem PM within each PEO would direct the development of uncrewed
system computing environments by software factories, which would permit independent development of vehicle control systems and C2 applications while ensuring quality, security, and version control of deployed software artifacts.

Software factories help streamline the process of integrating software associated with adaptable and resilient mission threads by providing a common environment for product development and delivery. The DoD has already created more than a dozen such factories, which a combination of government personnel and contractors operate. Most, like the Navy’s Black Pearl or Air Force’s LevelUp, focus on enterprise applications, but others, like the Air Force’s Kessel Run, are addressing near-term needs of operators in the field. Applying principles such as continuous integration, deployment, and delivery to enhance their efficiency, software factories can rapidly pull source code changes through an accredited pipeline and into operation. This stands in contrast to the traditional delivery model, in which manufacturers incorporate software into a system during production and update it only at periodic intervals thereafter.

From a defense acquisition standpoint, operating a software factory should be separate from developing and procuring uncrewed vehicles, crewed platforms, or mission systems. While some vendors seek a return to the twentieth-century model in which they could be the lead system integrators for an entire SoS, this approach would constrain the government’s ability to create or evolve novel mission threads. The alternative construct depicted in figure 16 would federate the process of digital integration by creating separate vendor pools and program offices for mission systems, crewed or uncrewed platforms, and the SoS software ecosystem. The Navy is adopting some elements of the proposed ecosystem model by establishing a firewalled vendor as an autonomy baseline manager (ABM) to oversee the overarching C3 software ecosystem for USVs and UUVs, which a combination of government and contractor software factories could develop and manage.80

The Navy is also applying principles of the structure in figure 16 through its JADC2 initiative, Project Overmatch, which digitally integrates communications technologies and C2 systems of carrier strike groups (CSGs). By using an accredited software factory to integrate successive CSGs as they prepare to deploy, Project Overmatch provides an organized and comprehensive approach to digital integration. It is not yet incorporating mission systems or vehicle control systems from uncrewed systems, but the Navy intends to extend its efforts to these use cases.81

The Navy’s construct for digitally integrating SoS that incorporate uncrewed elements is still evolving but is moving in the direction that figure 16 suggests. As in Project Overmatch and like the iOS ecosystem, the Navy generally seeks to separate software for uncrewed vehicle control, mission systems, and
planning tools to enable modularity and allow for open architectures that could increase SoS interoperability and recomposability. For example, the Navy has pursued common control system (CCS) software for C2 and control of air vehicles, including the MQ-4C, MQ-25, RQ-21, and MQ-8C Fire Scout. This is unlikely to be the only C2 solution for every future UAV, which, at minimum, will come with its own existing guidance and control capability for engineering development. Additionally, the software on mission systems that vehicles carry often cannot interface with CCS and instead communicates directly with offboard networks that sensor operators use.82

For uncrewed surface and undersea vehicles, the Navy PEO Unmanned and Small Combatants (PEO USC) is working with vendors to develop an Unmanned Maritime Autonomy Architecture (UMAA), which would establish government-owned interfaces between vehicle control systems, mission systems, and C2 and mission planning tools. The introduction of UMAA is consistent with recent legislation that reinforced the government’s right to intellectual property around any specified interface, including retroactive assertion.83 If the Navy successfully implements it, this model would achieve the Navy’s goals of rapidly recombing software modules for vehicle control, mission systems, mission planning, and C2. However, the success of commercial application program interfaces (APIs) suggests that UMAA should not establish standardized interfaces but should instead focus on exposing the interfaces for mission systems and other digital elements. This would enable software developers to work based on as-is interfaces rather than a standard that is unlikely to be perfectly implemented by the myriad of systems interacting with the ecosystem.

Digital models of real systems and simulation environments will be essential elements of digital integration. As noted above, digital twins will support the development of concepts and mission threads using M&S as part of Function 2, but they can also fill in—by using LVC environments—for real-world systems that are unavailable during experiments. By combining real hardware-in-the-loop systems with digital models or “digital twins,” LVC environments can enable individual component providers to understand how their component interacts with the whole. Conducting more of this assessment in Function 2 will reduce the risk that integration will go poorly during Function 4.

As part of Function 4, digital models of real systems can also enable federated software development and integration testing. Extending the UMAA model, ecosystem PMs in each PEO would exert the government’s right under US law to own the interfaces between different software elements and to publish those interfaces for use by mission system, uncrewed vehicle, and C2 tool providers. They would require vendors to build their software so that it is compatible with the published interfaces for other elements in a mission thread. The ecosystem PM would establish a simulation environment populated with digital models of likely mission thread or SoS elements to enable vendors to test their work against a slate of reference cases. To validate all contributing vendors’ software as interoperable in the context of a mission, the ecosystem PM would run a series of integration exercises or gauntlets that place the onus for integration on developers rather than establishing the government or another vendor as a single lead systems integrator.

Function 5: Resourcing and Requirements

The mission integration activities described above require a wide range of resources, including government personnel, leased or purchased uncrewed vehicles and mission systems, software, support contractors, test ranges, and operating time from crewed vessels and aircraft. The challenges in obtaining and allocating funding for these resources hinder mission thread and SoS development by slowing the pace of DoD experimentation and limiting the variety of systems that the DoD can assess.84

In the proposed construct, the Innovation Office would plan and program funding for mission integration activities as the headquarters resource sponsor, similar to how the Navy funds Project Overmatch–related activities through the Digital Warfare
Office. The Innovation Office is well positioned for this role because it would work with commanders to define operational problems and lead identification of initial solutions through M&S and experimentation. However, as a headquarters resource sponsor, the Innovation Office generally would not have direct contracting authority. It would provide funding to PEOs, whose DevOps and ecosystem PMs would contract with vehicle, system, software, and service providers or transfer funds to government organizations, such as warfare centers, for experimentation and digital integration activities.

As noted above, most vehicles, crewed platforms, and mission systems associated with a new mission thread and related SoS would already be in the DoD’s inventory. The Innovation Office would work with DevOps PMs to procure SoS elements that are not already part of the US military portfolio to enable fielding prototype SoS for commanders to assess under Function 6. Based on the results of experimentation, commanders’ feedback on how the prototype SoS addressed operational problems, and other PMs’ assessments regarding the sustainability of vehicles and mission systems, the Innovation Office and DevOps PM would lead validation of the SoS’s characteristics as new requirements under processes such as the DoD’s MTA acquisition path.

Under the process this study proposes, the Innovation Office would need a way to fund the new SoS until incorporated into the next DoD budget plan, which would start two or more years in the future. Initially, internal reprogramming actions that the Navy comptroller and the DoD comptroller can approve could provide this. A more enduring solution would be to provide the Innovation Office “wedge” PE lines, or to adopt a portfolio budgeting construct, that it could apply to mission integration actions, similar to the appropriations that DARPA or the Missile Defense Agency uses to fund R&D efforts. With broader PE lines, the Innovation Office could jump-start procurement of the new SoS promptly after the requirements are validated.

The broader PE lines provided to the Innovation Office would still follow the strict reporting and use-of-funds guidelines set out in financial management rules and appropriations law. However, instead of focusing on a particular vehicle and its subsystems, these PE lines would not specify the particular systems the DoD is integrating but instead fund system development, integration, and tests that are associated with a capability or mission, such as mine warfare or naval deception, using the examples of chapter 3. These lines would likely need to span all appropriations categories, from RDTE and O&M to personnel and procurement, to accommodate successful capability delivery. Establishing dedicated funding for SoS integration would also help uncrewed systems and new mission thread delivery compete with the funding needs of legacy platforms in the Navy’s budget development process.

**Function 6: Conducting Operations and Refining Systems**

It will be necessary to assess the new SoS that emerges from the mission integration process as a prototype before validating its characteristics as requirements for acquisition. And even if an SoS functions perfectly initially, the evolution of adversary capabilities and concepts, emerging technologies, and changing US posture could necessitate adjustments in the composition or mission thread of a new SoS. Under the proposed construct, operational commanders would lead the continued refinement of new SoS under Function 6 with the Innovation Office in support.
RECOMMENDATIONS AND CONCLUSION

The Navy and DoD could gain significant operational advantages by deploying uncrewed vehicles at scale to support a diversity of mission threads and SoS. Against a resident major power like the PRC, the US military cannot continue to rely on its historical dominance to deter and defeat aggression. Instead, the DoD will need to use a force that is less predictable, more adaptable, and increasingly resilient to attack the PLA’s strategy of system destruction warfare and its decision-making processes. By rapidly growing the variety of effects chains that are possible with US military forces without the costs associated with crewed platforms, uncrewed systems can undermine PLA planning and concepts and afford US forces the capacity to sustain a protracted conflict.

But uncrewed systems can only afford low cost, attritability, and reduced personnel requirements—and therefore, scale—if they are not multi-mission capable. Therefore, the DoD will need to employ them as part of SoS with other uncrewed systems and crewed platforms. This challenge will exacerbate the US military’s long-standing struggles to combine forces between and within each service branch. Realizing the benefits of uncrewed systems will demand that the DoD establish routinized processes for integrating new mission threads and SoS. Otherwise, the US military services will continue attempting to field uncrewed systems that replace crewed platforms in existing use cases.

US military services are already pursuing mission integration through initiatives in concept development, experimentation, rapid acquisition, digital integration, and JADC2. However, as

Photo: A global advanced reconnaissance craft is deployed in the Pacific Ocean during the US Pacific Fleet’s Integrated Battle Problem (IBP) 23.1 on May 3, 2023. (US Navy photo by Mass Communication Specialist 3rd Class Derek Kelley)
described in this report for the US Navy, these efforts are generally not well synchronized, focus on long-term service objectives rather than near-term operational problems, and use a top-down approach of systems engineering to guide requirements for future systems rather than a bottom-up process that exploits the systems and technology that are available today.

To bring uncrewed systems into the force more quickly and to realize their benefits, the DoD will need to recompose its mission threads to incorporate uncrewed systems where it can best use them, instead of attempting to build uncrewed systems that extend or replace crewed platforms. As in a commercial distribution warehouse, the fastest and most effective way to assimilate robotics is to adjust the organization’s workflow as opposed to developing robots to replace humans in existing workflows.

To evolve the DoD’s current processes and implement mission integration, this study recommends the following reforms:

1. **Formalize a mission integration process that would conduct the six functions of SoS development described in chapter 4 to address near-term combatant commander operational problems.**

   Each of the services should conduct the functions of problem definition, solution development and experimentation, material procurement, digital integration, resourcing and requirements, and operational refinement as part of their organize, train, and equip responsibilities. Mission integration will also be necessary at a defense-wide level to focus on those combatant commander operational problems that demand joint mission threads and SoS.

   While mission integration would be the main path to fielding new uncrewed systems, the services should continue their processes of systems engineering and requirements generation to satisfy long-term projected needs for crewed platforms and other capital investments.

2. **Establish an Innovation Office as the resource sponsor for SoS development and manager of the mission integration process.**

   The Innovation Office would need funding across multiple appropriation categories and the ability to validate requirements in concert with the appropriate service or Joint Staff offices. In the near term, the DoD could create an Innovation Office by reorganizing existing service or DoD organizations and their associated funding. Over the longer term, it should assign the Innovation Office funding in broad PE lines like those it uses in defense-wide R&D to enable the prompt transition of promising SoS into procurement and fielding.

3. **Create DevOps program manager (PM) roles in service PEOs and in the Office of the Secretary of Defense (OSD).**

   DevOps PMs would help synchronize and accelerate the mission integration process by contracting for a variety of services and procurement or by moving funding to other government offices to support analysis and experimentation. The services should establish DevOps PMs to support mission integration efforts within each PEO that oversees uncrewed systems, and OSD should establish one for joint mission threads within the Office of the Under Secretary for Research and Engineering (OUSD R&E) or the Office of the Under Secretary for Acquisition and Sustainment (OUSD A&S).

   The establishment of DevOps PMs will mark a significant cultural shift by bringing acquisition professionals into the experimentation and requirements process. However, connecting experimentation and acquisition is appropriate when available technologies are increasingly able to meet current and anticipated military needs and when a more rapid introduction of new capabilities is essential to gaining an operational advantage.

4. **Create ecosystem PM roles in service PEOs and in the OSD.**

   Software is increasingly the source of military capability and advantage in new weapons, mission systems, and vehicles. Soft-
ware is also the mechanism by which military forces integrate today, much as past generations integrated through doctrine and procedure. The DoD should establish PMs in each acquisition PEO to manage the development and maintenance of SoS software environments.

As described in chapter 4, ecosystem PMs would own government interfaces like the UMAA that connect vehicle, mission system, and C2 software and would oversee the integration of new systems into the ecosystem. Rather than taking more software development work into the government, the establishment of ecosystem PMs would enable the government to manage and oversee software development efforts by vendors, including software factories that maintain C3 environments and gauntlets in which new system providers demonstrate their ability to digitally integrate with the ecosystem.

**Conclusion**

In an environment where dominance is no longer a given, the US military needs to return to operational innovation. Historically, US forces have excelled when given the tools and processes to improvise and be creative. Many of the pieces necessary to enable effective innovation through mission integration are already in place. Accelerating and realizing the benefits of uncrewed systems will require better orchestration and execution of these activities to solve today’s operational problems. If the Navy and DoD fail to do so, they may miss their best opportunity to gain an enduring advantage against peer opponents like China.
ENDNOTES


19. Merriam-Webster’s Dictionary defines autonomous as “under-taken or carried on without outside control; existing or capable


36 The existing advanced driver assistance systems (ADAS) market is worth almost $50 billion annually, far larger than revenue that self-driving companies generate; see market report from Mordor Intelligence, “Advanced Driver Assistance Systems Market Size & Share Analysis—Growth Trends & Forecasts (2023–2028),” accessed July 15, 2023, https://www.mordorintelligence.com/industry-reports/advanced-driver-assistance-systems-market. Consider that key automotive suppliers like Magna and Bosch have acquired personnel and assets from defunct self-driving start-ups like Five.ai and Optimus Ride.

37 Examples include GM’s Super Cruise, Ford’s Blue Cruise, Tesla’s Autopilot, and Mercedes-Benz’s Drive Pilot.

38 New, more iterative, acquisition approaches have had limited success due to difficulties in oversight and execution; see Government Accountability Office, *Middle-Tier Defense Acquisitions: Rapid Prototyping and Fielding Requires Changes to Oversight*


44 Andrew F. Krepinevich Jr., Maritime Competition in a Mature Precision-Strike Regime (Washington, DC: Center for Strategic and Budgetary Assessments, 2016), 82.

45 Consider the case of mobile robotic bases that transport manipulator arms. Such a robot could perform both item- or box-picking tasks and transportation tasks. However, no commercially viable solution emerged in the ten years from 2013–2023 despite many attempts. Consider, for example, the Fetch mobile manipulator, introduced in 2014, which still has not found commercial application although simpler mobile bases have; see Evan Ackerman, “Fetch Robotics Introduces Fetch and Freight: Your Warehouse Is Now Automated,” IEEE Spectrum, April 29, 2015, https://spectrum.ieee.org/fetch-robotics-introduces-fetch-and-freight-your-warehouse-is-now-automated. Or consider the repeated terminations of robotics projects at Alphabet, including those that attempted to combine mobility with manipulation; see James Vincent, “Google Parent Alphabet Shuts Down Yet Another Robot Project,” The Verge, February 24, 2023, https://www.theverge.com/2023/2/24/23613214/everyday-robots-google-alphabet-shut-down.


54 The systems engineering V is the model that MIL-STD-499 formalized. While some view systems engineering through a more holistic lens, many others conflate the top-down V-model with systems engineering itself; as textbooks reflect, “The Systems Engineering Process (SEP) is a comprehensive . . . process, applied
This report primarily uses the term mission thread, which has increasingly widespread usage in the defense community. However, the term should be related to two adjacent concepts: mission workflows and kill chains. As we use it in this report, mission workflow is the most general concept, referring to a sequence of physical and informational process steps that a force executes in accomplishing a particular military objective. Practitioners will intuitively recognize that there are limits to routinizing the specifics of a mission workflow given the stubborn persistence of friction and adversary action. However, the sets of tools and courses of action often follow similar templates. The portion of a mission workflow that specifically concerns only the information flows and mission systems is called a mission thread. See, for example, Michael J. Gagliardi, William G. Wood, and Timothy Morrow, *Introduction to the Mission Thread Workshop* (Pittsburgh, PA: Software Engineering Institute, 2013), https://resources.sei.cmu.edu/library/asset-view.cfm?assetid=63148. In other words, a mission thread is a sequence of end-to-end information processing and distribution activities and events that members of a SoS perform in the conduct of a mission. A kill chain is a particular type of mission thread that focuses only on the find/fix/target/engage/assess aspects of a mission thread associated with one delivered effect.

The National Defense Authorization Act (NDAA) for Fiscal Year 2017, Section 855, directed the DoD to establish Mission Integration Management (MIM), the synchronization, management, and coordination of concepts, activities, technologies, requirements, programs, and budget plans to guide key decisions focusing on the end-to-end mission. The DoD responded by creating a Mission Engineering function that it modeled after systems engineering. See, for example, Under Secretary of Defense for Research and Engineering (USD R&E), *Mission Engineering Guide* (Washington, DC: US DoD, 2020), https://ac.cto.mil/wp-content/uploads/2020/12/MEG-v40_20201130_shm.pdf. Consider, for example, figure 2.4, which presents the decomposition of a mission thread into engineering system elements, a direct analogy to the top-down systems engineering V process. While discussion of mission threads has proliferated in the department, the Mission Engineering practice has yet to see widespread adoption, likely because of the unwieldy complexity.

There is a considerable set of evidence that a top-down model is never appropriate for sufficiently complex systems-of-systems. This shows up in, for example, large software systems. For one early examination of the scalability limits of systems engineering, see Barry Boehm, “Some Future Trends and Implications for Systems and Software Engineering Processes,” *Systems Engineering* 9, no. 1 (Spring 2006): 1–19, https://doi.org/10.1002/sys.20044.


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75 These are currently PEO Unmanned and Small Combatants (PEO USC) for UUVs and USVs, and PEO Unmanned and Weapons (PEO U&W) for UAVs.

76 See the extended discussion on “thinking in service levels” found in Weiss and Patt, *Software Defines Tactics*.


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83 See 10 USC 4401: Requirement for modular open system approach, as modified by the 2021 National Defense Authorization Act, § 804, and associated intellectual property law on segrega-
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84 Eric Lofgren, “What Does DoD Find to be the ‘Biggest Chal-
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