SEPTEMBER 2025

Event-Derived Defense Industrial Base Framework

Will Reichard-Flynn and Alix Preston

DRM-2025-U-042373-Final

CNA

Abstract

Because of system complexity and data disaggregation, most analyses of the US defense industrial base (DIB) are either data based with a narrow focus or are DIB-wide but rely on high-level synthesis. This report provides a middle ground in terms of scope by combining literature reviews with systematic categorization of weapon program events spanning more than a decade. We group consistent patterns to form a tiered framework in the categories of development, program management, production, and workforce. We then present case studies demonstrating the effect of these factors on program success using our framework. We found that factors internal and external to the Department of Defense (DOD) strongly affect project outcomes. We recommend that DOD prioritize addressing internal deficiencies (e.g., design, testing, and management practices) rather than trying to significantly influence external factors (e.g., workforce and supply chain issues).

This work was funded internally by CNA.

Cover image: Maintaining Malmstrom AFB's nuclear infrastructure. Photograph by Senior Airman Mary Bowers, April 8, 2025.

Approved by: **September 2025**

Timothy A. Roberts, Research Program Director
Strike and Air Warfare Program
Systems, Tactics, and Force Development Division

Executive Summary

Reform is necessary within the US defense industrial base (DIB) to deliver effective weapons on time and within budget.[1] A large body of work exists assessing the problems, root causes, and possible solutions to the greatest challenges facing the DIB. Yet because of system complexity and data disaggregation, it is difficult for analyses of the DIB to be based on data while capturing system-wide dynamics. Most analyses are either data based, but with a narrow focus, or are DIB-wide, but rely on high-level conceptual synthesis and inference. This report conducts a medium-scope evaluation of the challenges faced by the US DIB, combining a literature review with event-based evidence from acquisition programs to construct a novel framework. The framework covers the development, program management, production, and workforce aspects of DOD's acquisition process. Although this report places special focus on the Navy, the framework can be applied to the programs of all services.

We applied our framework to two specific examples: the development of the Air and Missile Defense Radar (AMDR) (or AN/SPY-(V) 1) and the Columbia-class submarine program. The first example was chosen because it demonstrates success in terms of budget, capability, and timeliness, and the second was chosen because it is a high-importance, high-cost, and high-complexity program that has faced significant disruptions. Applying the framework to the AMDR program shows how pragmatic design choices (e.g. sacrificing capability for achievability, prioritizing versatility) helped the program meet expectations, then expand to achieve economy of scale. Program management was also important to the AMDR program, where highly complex software (a major risk factor to AMDR) was developed successfully through iterative coordination between test organizers and software developers. Applying the framework to the Columbia program reiterates well-known production issues, where a small and inexperienced workforce has contributed to slower work and costly mistakes. However, it also emphasizes the less-discussed effects of design and program management, where unrealistic planning, substandard design tools, simultaneous design and production, and communication deficiencies, among other factors, contributed to delays and increased costs.

By developing and applying our framework, we found that there are many paths to strengthening the DIB, including targeted training programs, facility improvements, iterative testing, critical sector investments, and implementing best-practice requirements. Although external industry factors strongly affect the US DIB, internal factors also determine program success. Although external challenges (e.g., workforce shortages, multinational supply chain disruptions) often occur late in the program lifecycle, mistakes due to internal factors (e.g., DOD organizational structure, policy, design decisions) occur early and have compounding effects. Unlike external DIB factors, internal factors are directly under DOD's control. To improve acquisitions, DOD must change its internal operations.

[1] This summary contains text generated by OPNAV GPT and modified by the authors. For information regarding the machine-generated text in this report, see Appendix: AI Use Disclosure.

Table of Contents

PAGE INTENTIONALLY BLANK

Introduction

Defense acquisition—and its components of research, development, testing, evaluation, production, and procurement—delivers the essential technologies the military requires. The US defense industrial base (DIB) comprises a network of contracted commercial entities, government-owned facilities, and governmental oversight and decision-making bodies that facilitate acquisition.

The Navy, like other services, struggles to produce and maintain its capabilities on time and within budget [1]. The *2025 Navy Shipbuilding Plan* sets the Navy's intentions to increase the fleet size from 295 to 390 ships by 2054, requiring faster paced shipbuilding and a budget growth of 46 percent [2]. Such a pace will be difficult to achieve given challenges within naval shipbuilding, where vessels move from contract to delivery on timelines two to four times longer than those of commercial ships [3]. Even as pressure mounts to increase the size of the fleet, the Navy faces challenges maintaining its current inventory, estimating a maintenance backlog of approximately $1.8 billion [1]. Acquisition challenges do not afflict shipbuilding alone. It is more common for high-profile weapon programs to miss milestones than to meet them, and acquisition budgets increase by billions of dollars each year [4]. For the Department of Defense (DOD) to meet current and future challenges, it must improve the DIB.

A large body of work exists assessing the problems, root causes, and possible solutions to the greatest challenges facing the US DIB. Yet because of system complexity and data disaggregation, it is difficult for analyses of the DIB to be based on data while capturing system-wide dynamics. Most analyses are either data based, but with a narrow focus, or are DIB-wide, but rely on high-level conceptual synthesis and inference. This report, as part of CNA's independent research program, provides a middle ground between these scales of assessment. We combine a literature review with specific events within weapon programs spanning more than a decade to evaluate the holistic DIB system. We group consistent patterns to form a tiered framework in the categories of development, program management, production, and workforce. This report places a special focus on Navy programs, including unique challenges facing shipbuilding. However, the framework is built from programs across the DOD and may apply to other services as well.

The first section of this report justifies the framework point by point using supporting literature and examples from weapon programs. The second applies the framework to selected Navy acquisition programs to highlight key green and red flags, which we call "indicators." Finally, we examine how patterns in the framework itself can help us understand the greatest challenges in the US DIB and the most effective paths toward solving them.

DIB Framework

The framework we developed concisely describes common features that affect the success or failure of acquisition programs. This framework can be used to identify indicators that may put a program at risk, or simply to help conceptualize drivers in a highly complex system.

To create the framework, we performed a literature review of DIB-related reports (e.g., sector assessments, contractor surveys), news articles, policies (e.g., *National Defense Industrial Strategy, Navy Shipbuilding Plan*), and information from a variety of sources, such as federally funded research and development centers, the US Government Accountability Office (GAO), and the Congressional Research Service. From this review, we identified high-level categories (development, program management, production, and workforce) and more specified subcategories (e.g., technology maturity, contractor relations, supply chain) that broadly describe components of the DIB (Table 1). Next, we examined the GAO's yearly *Weapon Systems Annual Assessments* [4-18] to identify specific examples of when a program was disrupted, why it was disrupted, and the resulting consequences. We used these examples to further build out our indicators within each subcategory. As more examples were included, we adjusted the framework to include as few sections as possible while still accurately categorizing each event. All indicators are supported by at least one event, except "IP management" and "Sufficient number of production/maintenance facilities." We include these indicators nonetheless because of strong support in professional and academic literature.

Table 1. DIB framework

Category	Subcategory	Indicator
Development	Technology maturity	Critical technology is mature early in design process
		Critical technology is mature by production
		Existing tech and designs used when possible
	Design rigor	Design is stable before production
		Software developed on time
		Design developed on time
		Design free of flaws
		Industry-standard design practices used
	Iterative design	End-users influence design
		Testing prompts redesign, and redesign prompts testing
		Technologies without business case off-ramped
	Testing rigor	Operationally realistic testing
		Environmentally realistic testing
		High-quality testing
		Timely testing
		Test ranges available
		Balanced test prioritization

Program management	Contractor relations	Appropriate penalties employed
		Effective IP management
		Sufficient contractor capacity
	Requirements	Requirements follow best practices
		Requirements are up to date
		Application of sector-appropriate oversight
	Funding	Funding consistency
		Realistic cost estimation
		Cost reduction efforts
	Cross-program management	Maturity of required assets
		Availability of required assets
		Clear delineation of program responsibility
		Interoperability
Production	Supply chain	Part and material availability
		Stability of material costs
		Early identification of hard-to-obtain components
		Surge capacity
	Infrastructure	Sufficient number of facilities
		Sufficient quality of facilities
	Production rigor	Product quality
		Production maturity achieved before full-rate production
		Production efficiency
		Active risk mitigation
		Realistic production schedule
Workforce	N/A	Sufficient workforce size
		Sufficient experience level
		Workplace attractiveness

Source: CNA.

Development

Every program begins with initial design choices that have a lasting effect through production and operation. Design and testing are inextricably linked: iterative cycles of design, prototyping, and testing repeat through all phases of the program life cycle to guide decision-making and identify problems.

Using existing technology decreases cost, development time, and risk. When no suitable technology exists, critical technology should be matured early in development to avoid cascading effects on system design and production. If a capability cannot be matured on schedule, it should be adjusted or eliminated ("off-ramped"). Iterative design folded in with frequent, high-quality testing helps identify problems early and keeps the program on track with up-to-date operational needs. The following sections discuss the importance of technology maturity, design quality, design schedule, iterative design, test quality, and test schedule in program development. For each of these subcategories, we identify indicators, or the actions or attributes that have historically affected programs.

Technology maturity

	Subcategory	Indicators
Development	**Technology maturity**	**Existing tech and designs used when possible; critical technology is mature early in design process; critical technology is mature by production**
	Design rigor	Design free of flaws; industry-standard design practices used; design is stable before production; design/software developed on time
	Iterative design	End-user influences design; testing prompts redesign, and redesign prompts testing; technologies without business case off-ramped
	Testing rigor	Operationally and environmentally realistic testing; high-quality testing; timely testing; test ranges available; balanced test prioritization

The military's unique needs demand the development of new technology. Consequently, new programs will almost always introduce technology that must be matured. New technology is a source of risk, particularly when development is concurrent with design and production. Delayed or flawed development can lead to costly redesign and refurbishment.

To mitigate risk, established technologies should be used whenever possible. Designs with high customization prevent the Navy from implementing commercial solutions that could be quickly and cost-effectively adapted [19]. For example, one strength of the People's Republic of China's People's Liberation Army Navy is its dual-use shipyards, which produce both military and commercial ships with minimal changes in the building process [20]. Maintaining a high volume at a consistent production tempo benefits workforce stability, speed, cost, and capacity [3, 20]. However, when a high degree of customization is introduced, friction arises between military acquisitions and commercial interests. Although some aspects of military acquisitions have unique requirements, unnecessary customization comes at the cost of diminished scale of production, long development timelines, higher expense, obsolescence, diminished industrial base resilience, maintenance issues, and low interoperability [19]. Example effects of technology maturity on acquisitions are shown in Table 2.

Table 2. Example effects of technology maturity on acquisitions

Indicator	Supporting examples
Critical technology is mature early in the design process	**Ballistic missile defense system (BMDS) ground-based midcourse defense (GMD):** The inclusion of immature technology led to substantial redesign [5].
	BMDS airborne laser (ABL): None of the technologies were mature before production decision, leading to testing delays [5].
	Other programs: Nuclear-powered ballistic missile submarine (SSBN) 826 [18], guided missile destroyer (DDG) 1000 [4], F/A-18E/F infrared search and track (IRST) [18], BMDS Aegis Ballistic Missile Defense (BMD) [5], BMDS Flexible Target Family (FTF) [5].
Critical technology is mature by production	**BMDS GMD:** Placed sensors before technologies were mature, then required refurbishment to address reliability issues [5].
	BMDS FTF: All six critical technologies were immature at beginning of production, leading to testing delays [5].
	BMDS Aegis BMD: Four out of five critical technologies remained immature at the beginning of production, leading to testing delays [5].
	Other programs: SSBN-826 [18], DDG-1000 [4], F/A-18E/F IRST [18].

Indicator	Supporting examples
Existing tech and designs used when possible	**F-22:** Developed Open Systems Enclave, which allows commercial software to run on the aircraft's systems [21].
	T-AO-205: Changed design to use a commercial diesel engine, a decision expected to reduce costs by $2–$4 million per hull [18].
	Nuclear-powered aircraft carrier (CVN) 78: Off-ramped Dual Band Radar for the Enterprise Air Surveillance Radar (EASR) used in other ship classes to ensure a more reliable supply chain and reduce the cost of spare parts [4].
	Air and Missile Defense Radar (AMDR): Off-ramped new x-ray radar technology in favor of existing technology and designed software to operate on commercial, off-the-shelf hardware [8].
	Advanced Anti-Radiation Guided Missile (AARGM): Used existing air-to-ground missile (AGM) High-speed Anti-Radiation Missile (HARM) propulsion and warhead sections [5].

Source: CNA.

Design rigor

	Subcategory	Indicators
Development	Technology maturity	Existing tech and designs used when possible; critical technology is mature early in design process; critical technology is mature by production
	Design rigor	**Design free of flaws; industry-standard design practices used; design is stable before production; design/software developed on time**
	Iterative design	End-user influences design; testing prompts redesign, and redesign prompts testing; technologies without business case off-ramped
	Testing rigor	Operationally and environmentally realistic testing; high-quality testing; timely testing; test ranges available; balanced test prioritization

Quality designs deliver capability and prevent costly rework. Design quality can be enhanced by using industry-standard design practices. For example, using 3-D rather than 2-D designs prevents multiple components from occupying the same space [3]. In some cases, the services maintain 2-D blueprints and outdated, error-prone files that do not meet contractors' quality expectations [22]. Outdated design technology is worse for older platforms, such as Arleigh Burke–class destroyers and Virginia-class submarines, which still use legacy 2-D designs [3].

Various pathways exist for improving design quality. For example, comprehensive design libraries such as those maintained in industry could make the design process faster and more reliable [3]. However, intellectual property (IP) concerns make such libraries more difficult to maintain for the DOD than for commercial entities [3]. Digital engineering techniques have no demonstrated cost benefits, but could offer performance benefits [23].

Design quality applies to software as well as hardware. The federal government spends $100 billion annually on information technology (IT), 80 percent of which goes to maintaining existing systems [24]. Legacy systems can be costly to maintain, require obsolete programming languages, and introduce security threats, all while providing an insufficient service to users [24].

Cybersecurity vulnerabilities are also present throughout the commercial DIB. It is expensive to maintain cybersecurity infrastructure and difficult to navigate federal cybersecurity regulations, meaning that the disparate sprawl of commercial entities that make up the DIB present points of vulnerability for IP and sensitive data [25]. Small DIB firms are often deficient in user authentication, network defenses, vulnerability scanning, software patching, and security information and event management [25].

Beyond the designs themselves, programs are affected by *when* the designs are completed. Delayed designs can postpone testing, and concurrent design and production can lead to costly rework. For shipbuilding, best practices suggest that (1) vendor-furnished information (VFI), basic design, and functional design should be complete before any construction, and (2) detail design for a given block should be complete before that block's construction [3]. Example effects of design rigor on acquisitions are shown in Table 3.

Table 3. Example effects of design quality on acquisitions

Indicator	Supporting examples
Design free of flaws	**CVN 78:** Reconfigurations to the Electromagnetic Aircraft Launch System (EMALS) and Advanced Arresting Gear (AAG) were a primary contributor to a $3.8 billion cost increase and placed the program at risk for future delays [4].
	DDG-1000: Design flaws led to biofouling and exhaust ingestion [18].
	Ship-to-Shore Connector Amphibious Craft: Design flaws led to cracking propeller blades and premature gearbox wear [18].
	SSBN-826: Flaws in design software led to delays and inflated the size of the design staff [15-16].

Indicator	Supporting examples
Industry-standard design practices used	**CVN 78:** Transitioning from paper to digital designs [4].
	MQ-4C: In 2024, the program was using an outdated cybersecurity strategy from 2015 [18].
Design is stable before production	**FFG-62:** Hampered by delayed VFI and placed at risk by simultaneous design and construction (90 percent of functional design and 80 percent of detail design was complete when construction began) [18].
	Other programs: DDG-1000 [4], F/A-18E/F IRST [18].
Software developed on time	**AARGM extended range (ER):** Software delays drove 7 months of operational testing delay and 9 months of initial capability delay [18].
	FFG-62: Software delivery has thus far been delayed by two years [4].
	AMDR: Despite substantial software demands, met criteria and consistently released iterative builds on time [13].
Design developed on time	**SSBN-826:** Delays in design delivery led to delays in construction [18].
	AMDR: Delivered 100 percent of design drawings before design review [11].

Source: CNA.

Iterative design

	Subcategory	Indicators
Development	Technology maturity	Existing tech and designs used when possible; critical technology is mature early in design process; critical technology is mature by production
	Design rigor	Design free of flaws; industry-standard design practices used; design is stable before production; design/software developed on time
	Iterative design	**End-user influences design; testing prompts redesign, and redesign prompts testing; technologies without business case off-ramped**
	Testing rigor	Operationally and environmentally realistic testing; high-quality testing; timely testing; test ranges available; balanced test prioritization

Acquisition programs take years or even decades to move from initial development to delivery. During that time, the operational and technical landscape can shift profoundly. Iterative design supports product quality and allows new requirements to be added while obsolete requirements are off-ramped.

Key principles for product development include attaining a sound business case, using an iterative design approach, off-ramping capabilities to prioritize schedule, and collecting user feedback on a minimum marketable product [26]. These best practices are not well supported by the DOD acquisition process, in which prescriptive requirements are set through a capability development document (CDD) [3]. Producing a CDD is a multistep process of design, commenting, adjudication, and approval, involving numerous stakeholders, which often takes years to complete [3]. Risk aversion has caused the number of DOD stakeholders to increase over time, making approval processes lengthy and administratively burdensome [3]. This process was addressed by Section 811 of the National Defense Authorization Act for Fiscal Year 2024, which prompts acquisition to be streamlined. In recent years, the Adaptive Acquisition Framework has expanded and strengthened alternative pathways to streamline acquisition. A prominent example is the Replicator program, which has demonstrated early success in rapidly delivering attritable autonomous systems.

An advanced capability is not necessarily an *effective* or *cost-effective* capability. This dilemma is evident in the Red Sea, where advanced weapons worth more than an aggregate total of $1 billion have been expended on cheap drones and missiles [27]. It is also evident in Ukraine, where weapons worth millions of dollars have been destroyed by low-cost drones [28]. Given finite resources, every acquisition decision is a trade-off: placing greater emphasis on quality necessarily places less emphasis on quantity and/or timeliness. The entrenched acquisition process prioritizes the execution of all planned capabilities above delivering a less capable platform on schedule [3, 26]. Emphasizing exquisite capability over timeliness can backfire, leading to technologies that are not delivered until they are already obsolete. An example is the DDG-1000, which took 11 years to begin construction, at which point military needs had changed and the number of ordered vessels was reduced from 32 to 3 [3]. Prioritizing timely delivery and iterative redesign allows the Navy to fight in a current conflict rather than a past conflict that has already ended or a future conflict that may never arrive. Example effects of iterative design on acquisitions are shown in Table 4.

Table 4. Example effects of iterative design on acquisitions

Indicator	Supporting examples
End-users influence design	**Littoral Combat Ship (LCS) packages:** Designs with high operational complexity caused testing challenges [4].
Technologies without business case off-ramped	**LCS packages:** Off-ramped antisubmarine warfare package in the face of delays and obsolescence [17].
	C-130 Avionics Modernization Program: After a Nunn-McCurdy cost breach, cut the program's six critical technologies in half [5].
	AMDR: Off-ramped new x-ray radar portion in favor of existing technology [8].
Testing prompts redesign, and redesign prompts testing	**Next Generation Jammer (NGJ) Mid-Band (MB):** Substantial software changes necessitated new testing [18].
	F-22: Open Systems Enclave allows developing third-party software to be tested on aircraft systems [21].

Source: CNA.

Testing rigor

	Subcategory	Indicators
Development	Technology maturity	Existing tech and designs used when possible; critical technology is mature early in design process; critical technology is mature by production
	Design rigor	Design free of flaws; industry-standard design practices used; design is stable before production; design/software developed on time
	Iterative design	End-user influences design; testing prompts redesign, and redesign prompts testing; technologies without business case off-ramped
	Testing rigor	**Operationally and environmentally realistic testing; high-quality testing; timely testing; test ranges available; balanced test prioritization**

To accurately assess performance, tests must capture operational and environmental realism and be completed with suitable rigor.[2] Realistic testing environments help identify potential flaws in systems that might not be apparent in controlled or ideal conditions, ensuring that the final product performs reliably under actual operational conditions. Realism can be difficult to achieve because of the costs and coordination involved. However, identifying and rectifying flaws during the testing phase is less costly than addressing issues that arise during deployment or operation and helps ensure that systems will serve the end users.

As with design, not only quality but also *timing* of testing is important. Flaws are an expected part of the acquisition process. Testing reveals flaws, and a flaw identified "on time" is less disruptive than a flaw identified later in development.

Testing consumes scarce program resources and often relies on facilities and platforms that must be shared across programs or objectives. Ensuring "on time" testing requires sufficient test-range infrastructure to support the portfolio and requires that coordination occurs across programs. Example effects of testing rigor on acquisitions are shown in Table 5.

Program management

The underlying policies and processes within acquisition programs are the levers of control that guide decision-making and influence the larger commercial DIB. Contractors play a major role in every stage of acquisitions. DOD must maintain good relationships with contractors to protect government interests while attracting highly capable commercial entities, which requires DOD to establish policy and practices that efficiently facilitate appropriate oversight. DOD's portfolio contains interdependent programs that compete for limited funding, labor, and testing resources and must therefore prioritize large-scale capability objectives over any individual program. On the topic of program management, the following sections discuss the importance of contractor relations, requirements, funding, and cross-program management. For each of these subcategories, we identified indicators, or the actions or attributes that have historically affected programs.

The contractor base is a major part of the DIB, consuming roughly half the defense budget [29]. Since the 1990s, the number of companies that make up the DIB has dramatically decreased (Figure 1). In the past 30 years, aerospace and defense prime contractors have shrunk from 51 to 5 entities, tactical missile suppliers from 13 to 3, and fixed-wing aircraft suppliers from 8 to 3 [22]. In the past decade, the number of small businesses in the DIB has shrunk by more than 40 percent [30]. From 2018 to 2023, 17,045 entities were lost from the defense ecosystem [31].

Although competition contributes to industry by lowering prices and improving services, consolidation is not inherently harmful to the DIB. The present landscape is the intended result of the "Last Supper" in 1993, during which defense firms were directed to merge in response to a shrinking defense budget [33]. Despite consolidation, competition has remained relatively stable over the past decade [22]. However, as commercially mature technology such as software and robotics becomes central to military operations, DOD's incentive to attract new DIB entrants has renewed.

[2] This section contains text generated by Morse Code (CNA's large language model) and modified by the authors. For information regarding the machine-generated text in this report, see Appendix: AI Use Disclosure.

Table 5. Example effects of test quality on acquisitions

Indicator	Supporting examples
Operationally realistic testing	**AARGM-ER:** Tests failed to capture operational performance [4].
	LCS packages: Tests individual packages rather than whole-system integration [17].
Environmentally realistic testing	**NGI MB:** Tests performed in a limited range of flight conditions that do not capture requirements [18].
	CH-53K Heavy Lift Replacement: No wind tunnels large enough for system, required tests to be performed on scaled-down prototypes [5].
	Other programs: AARGM-ER [18], DDG-1000 [4], LCS packages [17].
High-quality testing	**LCS packages:** Completed tests must be repeated because of insufficient data collection [17].
Timely testing	**MQ-25:** Before low-rate production, prototype testing identified design flaws that could cause engine damage during flight [4].
	LCS packages: Will enter operations without planned capabilities because of a lack of testing on certain systems [4].
	BMDS GMD: Sensors were installed before technologies were tested in a realistic environment and later required refurbishment when flaws were discovered [5].
	T-AO-205: Testing delays led to a 20-month delay in lead ship delivery [18].
	AMDR: Completed rigorous testing of critical technologies early in development, bringing them near maturity [10].
	Other programs: AARGM-ER [17], MQ-4C [18], BMDS Terminal High-Altitude Area Defense (THAAD) [5], DDG-1000 [18].
Test ranges available	**DDG-1000:** Faced delays while awaiting the development of test-range equipment [17].
	AARGM-ER and **BMDS ABL:** Delays due to unavailable test ranges [5, 18].
Balanced test prioritization	**DDG-1000:** The program has faced substantial delays, such as a 15-month operational test delay, due to the prioritization of fleet activity support [4, 17].
	MQ-4C: Faced conflicts balancing developmental and integrated testing [18].
	T-AO-205: Survivability testing delayed more than a year because of ship availability [18].
	LCS packages: Cybersecurity testing delayed because of ship availability and test resources [17].

Source: CNA.

Contractor relations

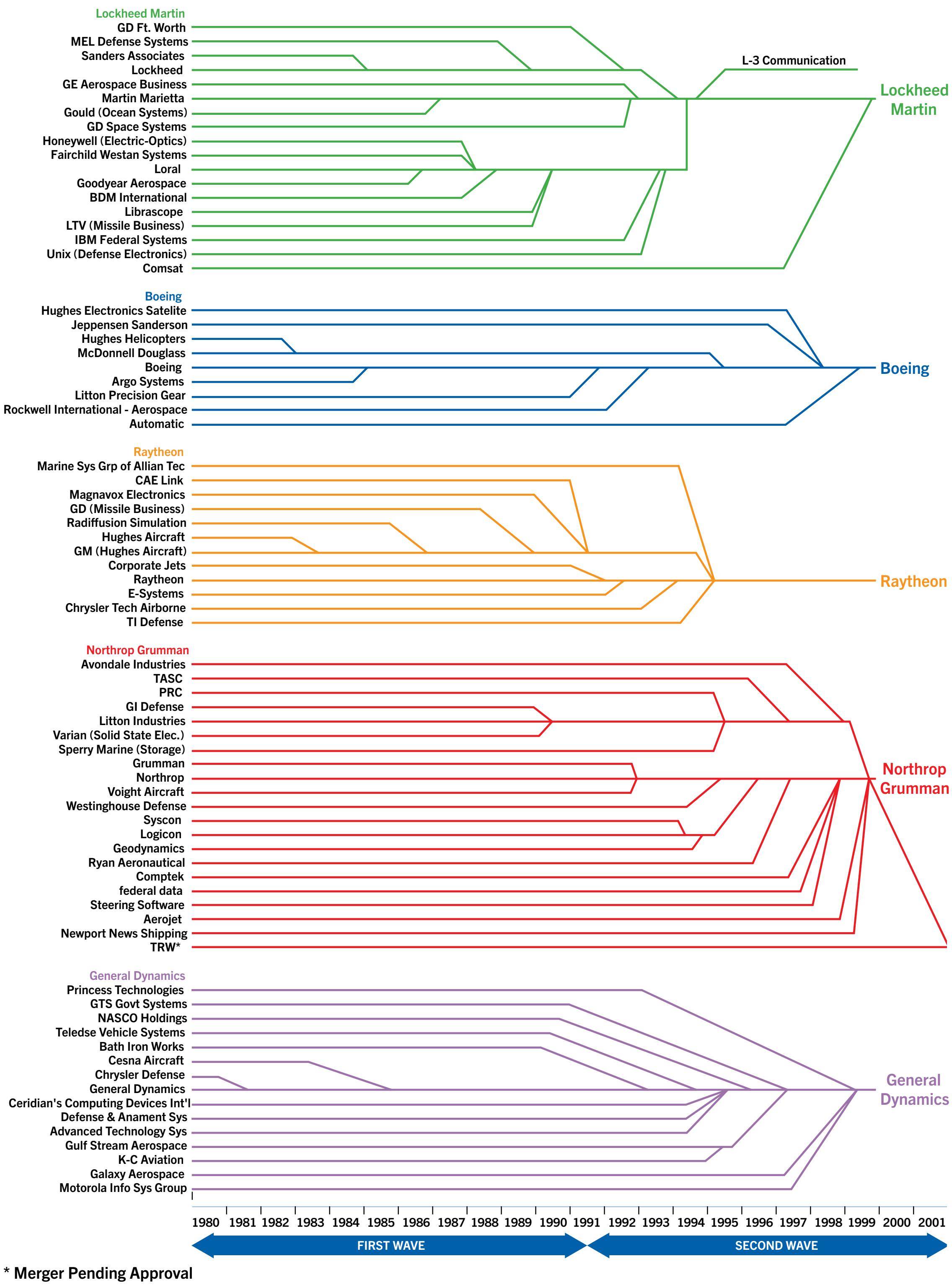
	Subcategory	Indicators
Program management	**Contractor relations**	**Appropriate penalties employed; effective IP management; sufficient contractor capacity**
	Requirements	Requirements follow best practices and are up to date; application of sector-appropriate oversight
	Funding	Funding consistency; realistic cost estimation; cost reduction efforts
	Cross-program management	Maturity and availability of required assets; clear delineation of program responsibility; interoperability

Traditional and nontraditional DIB entities can cooperate in the cumulative procurement landscape, where large prime contractors provide institutional knowledge, bureaucratic infrastructure, and resilience while small startups provide innovation and agility. Startups may contract directly with DOD (e.g., Anduril's Roadrunner/Pulsar, a reusable, artificial intelligence–enabled uncrewed aerial vehicle interceptor [34]), or may partner with established "Big Five" prime contractors (e.g., HawkEye 360 [35]).

DOD is increasingly reliant on commercial purchases to speed procurement and enhance capability; for the past decade, commercial items have made up approximately 90 percent of all procurements [22]. However, conflicting interests over IP rights are a concern in commercial acquisitions. Commercial IP ownership can diminish competition in the defense space, place DOD at the mercy of "vendor lock," and leave DOD with obsolete products it is unable to update or integrate [22]. However, overly restrictive IP policy can limit the products DOD receives. A National Defense Industrial Association (NDIA) survey of DIB entities showed that 21 percent of respondents elected not to bid on certain projects and 28 percent chose not to place certain technologies in bids because of IP concerns [36].

Some sectors of the DIB are a monopsony, or a market where there are multiple vendors but only one buyer, which could hypothetically grant DOD greater pricing power. However, to preserve necessary, specialized services, DOD must shelter DIB entities to some extent, diminishing monopsonistic pricing power [37]. Combined with a highly consolidated contractor base, this can lead to products being priced above their value [38]. Contractor management requires DOD to find a balance between penalties and incentives such that it attracts highly capable commercial entities while protecting its own interests. Example effects of contractor relations on acquisitions are shown in Table 6.

Figure 1. Consolidation in the DIB contractor base



Source: [32].

Table 6. Example effects of contractor relations on acquisitions

Indicator	Supporting examples
Appropriate penalties employed	**AMDR:** Program faced $1.3 billion in contractor overruns; contractor offered warranty after disruptions caused by faulty components [17].
	MQ-25: Boeing went over budget and schedule, but bears costs because of fixed-price contract [39].
	T-AO-205: Program faced $164.5 million in contract overruns [4].
	AARGM: Contract contains incentives for on-time delivery [5].
Effective IP management	No examples.
Sufficient contractor capacity	**AARGM-ER:** Delays due to contractor's difficulty managing DOD customer workload [18].
	FFG-62: Delay as a new contractor set up subcontractors and supply chain [17].

Source: CNA.

Requirements

	Subcategory	Indicators
Program management	Contractor relations	Appropriate penalties employed; effective IP management; sufficient contractor capacity
	Requirements	**Requirements follow best practices and are up to date; application of sector-appropriate oversight**
	Funding	Funding consistency; realistic cost estimation; cost reduction efforts
	Cross-program management	Maturity and availability of required assets; clear delineation of program responsibility; interoperability

Requirements must maintain a balance between critical guidance and harmful overprescription. Ineffective requirements can affect the fundamental machinery that supports acquisitions. For example, data collection and sharing improves DIB operations by increasing supply chain visibility, disseminating lessons learned, identifying price gouging [38], and enabling root-cause analysis in supply, production, and maintenance [19]. Reliable and accessible data from government and commercial portions of the DIB are necessary to fulfill the goals of the 2022 National Defense Strategy for systematic supply chain visibility. However, achieving data visibility is hampered by disaggregated DOD organizations that operate without central authority and are often motivated by fear of violating contracts and regulations [40].

The National Defense Authorization Act for Fiscal Year 2022 initiated new policy requiring ship design maturity assessment. However, the policy leaves out several best practices, such as the requirement of 3-D designs, demonstration of the positioning and routing of major distributive systems, detailed design prior to ship block construction, and an understanding of VFI completeness [3]. The effects of selecting metrics that are not properly tied to design maturity can be seen in the FFG-62 program, which technically satisfied the Navy's design metrics, but is now facing schedule and cost challenges due to design flaws [3].

A study on the casting and forging industry (a DIB priority sector [22]) reports that long communication delays and approval requirements disrupt production schedules and waste resources for DIB entities [41]. In an NDIA survey, DIB respondents ranked federal budget processes and complex, protracted procurement processes above the supply chain as the most pressing problem facing the DIB [36].

Although production benefits from best-practice requirements, poorly formulated requirements and inefficient government processes can impede acquisitions. Shipbuilder designs (which number in the hundreds) are allotted 21 to 60 days for approval [3]. This turnaround time is much longer than that of commercial shipbuilding, where a maximum of 21 days can be expected [3]. Risk aversion has caused the number of DOD stakeholders to increase over time, making approval processes lengthy and administratively burdensome [3].

Defense contractors can also adversely influence requirements. According to OpenSecrets, defense contractors spent nearly $150 million in lobbying efforts in fiscal year (FY) 2024, which may encourage decision-making that prioritizes the interests of contractors above national security [58]. Example effects of requirements on acquisitions are shown in Table 7.

Table 7. Example effects of requirements on acquisitions

Indicator	Supporting examples
Requirements follow best practices	**SSBN-826:** Five critical technologies were not identified because Navy requirements deviated from best practices. As a result, critical technologies will not mature until late into production, placing the program at risk [16].
	AMDR: Technologies were deemed mature by DOD requirements, but not by best practices requiring demonstration in an operationally realistic environment [13].
	FFG-62: Met DOD standards for design completion, but did not meet best practices [18].
Requirements are up to date	**MQ-4C:** In 2024, the program was using an outdated cybersecurity strategy from 2015 [18].
Application of sector-appropriate oversight	**MQ-25:** After severe production quality issues, the program placed subject matter experts on site at sub-tier suppliers and wrote manufacturing data requests into contract [17]. The program failed to provide detailed software requirements, resulting in delays [4].
	SSBN-826: A failure to provide high-quality, timely work instructions to an inexperienced workforce resulted in construction delays [18].
	B-2 Spirit advanced extremely high frequency (AEHF) satellite communication: Failure to provide software requirements resulted in a nine-month delay to testing and evaluation [5].

Source: CNA.

Funding

	Subcategory	Indicators
Program management	Contractor relations	Appropriate penalties employed; effective IP management; sufficient contractor capacity
	Requirements	Requirements follow best practices and are up to date; application of sector-appropriate oversight
	Funding	**Funding consistency; realistic cost estimation; cost reduction efforts**
	Cross-program management	Maturity and availability of required assets; clear delineation of program responsibility; interoperability

A sound business case calls for consistent demand and consistent payment for a product or service. Changing needs and unstable budget processes cause inconsistent demand and payment from the federal government.

Predictable, steady, long-term production makes processes more cost-effective and preserves a skilled worker base [42]. However, the past 60 years of repeated boom and bust cycles in ship production have made the industry an unattractive space for DIB entities and workers [42]. In an NDIA survey of commercial DIB entities, the most commonly cited supply chain challenge was an unpredictable or inconsistent demand signal from the US government [36].

For 14 of the past 15 years, DOD has operated under a continuing resolution (CR), with the FY 2024 appropriation remaining unapproved until March 23, 2024 [36]. CRs prevent new programs from beginning on schedule, delaying delivery and injecting uncertainty that disincentivizes new entrants [43]. Without timely payment, workers are laid off, resources are wasted, and operations are disrupted [36].

Beginning in March 2024, Congress began approving two- to five-year contracts rather than annual contracts for munitions production [43]. This change facilitates stability and economy of scale estimated to generate savings anywhere between less than 5 percent to 15 percent [44]. However, multiyear contracts come at the cost of flexibility [44]. Example effects of funding on acquisitions are shown in Table 8.

Table 8. Example effects of funding on acquisitions

Indicator	Supporting examples
Funding consistency	**SSBN-826:** Construction delayed two years because of fiscal constraints, prompting an aggressive, high-risk pace of production [8].
Realistic cost estimation	**SSBN-826:** Multiple analyses suggest that the projected program costs are not achievable [13-14, 18].
	AMDR: Faced cost increase after over-optimistic cost-setting on part of contractor [4].
	C-5 Reliability Enhancement and Re-engining Program (RERP): Cost underestimates led to program restructuring and delays [5].
Cost reduction efforts	**SSBN-826:** Cost-reduction initiatives, such as a modified tube design, reduced early cost estimates from $5.6 billion to $4.9 billion per unit [5, 7].
	T-AO-205: Organized working group for cost reduction, the efforts of which are projected to reduce the unit cost by $72 million for each ship for deliveries 1-6, and $23 million for subsequent units. Changes include a reduced deckhouse size, lowering the unit cost by $7.2 million [18].
	C-5 RERP: Restructured program to account for upward cost pressures [5].

Source: CNA.

Cross-program management

	Subcategory	Indicators
Program management	Contractor relations	Appropriate penalties employed; effective IP management; sufficient contractor capacity
	Requirements	Requirements follow best practices and are up to date; application of sector-appropriate oversight
	Funding	Funding consistency; realistic cost estimation; cost reduction efforts
	Cross-program management	**Maturity and availability of required assets; clear delineation of program responsibility; interoperability**

Weapon programs are interconnected, relying on shared resources and one another for testing, development, and production. Maintaining the overall defense portfolio requires cross-program coordination, incorporation of risk because of program dependencies, and the allocation of scarce resources such as funding, personnel, test range access, and asset availability.

Interoperability requires that capabilities function with foreign as well as domestic systems. Ukraine's synthesis of weapons donated from numerous countries has identified interoperability gaps between the systems of allied nations that must be solved to maximize joint capability [45]. DOD also has a financial incentive to pursue the international interoperability necessary to secure Foreign Military Sales, which were valued at $117.9 billion in FY 2024, according to the Department of State's Bureau of Political-Military Affairs [46]. Example effects of cross-program management on acquisitions are shown in Table 9.

Table 9. Example effects of cross-program management on acquisitions

Indicator	Supporting examples
Maturity of required assets	**AARGM-ER:** Delays of more than nine months stemming from issues in the AGM-88E program [4].
	DDG-1000: Delayed while awaiting test range equipment development [17].
	F/A-18E/F IRST: Hardware delays contributed to software delays [17].
	BMDS THAAD: Multiple target failures resulted in "no test" outcomes and test delays [5].
	Airborne Signals Intelligence Payload: Developmental issues with the sensor's platform (Global Hawk) increased costs and caused delays [5].
Availability of required assets	**BMDS THAAD:** Did not assess medium-range capability because of target availability [5].
	LCS packages: Early retirement of the host platform resulted in low availability [17].
Clear delineation of program responsibility	**LCS packages:** Ambiguity in responsibility for cybersecurity fixes could lead to redundancy or vulnerability [17].
Interoperability	**MQ-25:** Set up ground control systems to be used by other uncrewed systems [16].
	SSBN-826: Design shares roughly 70 percent of parts with Virginia-class program [12].
	AMDR: Designed to be adaptable to multiple host platforms [5].

Source: CNA.

Production

Production comprises the supply and manufacturing processes associated with acquisition. Although a small portion of production stems from public facilities, most production activities rely on a complex and interconnected system of private commercial entities. This complexity is exemplified by the supply chain, where the fundamental components necessary for production come from fragile and complex pathways that are difficult to track. DOD systems are produced in relatively small quantities and often require nonstandard production processes. As a result, production processes often remain immature even as systems are delivered, which may lead to quality issues. Under these circumstances, production risk can be mitigated but not eliminated, and programs must actively assess and plan for disruptions. The following sections discuss the importance of supply chain, infrastructure, production maturity, and risk management on production. For each of these subcategories, we identified indicators, or the actions or attributes that have historically affected programs.

The supply chain faces new challenges (e.g., cyberattacks, climate change) as well as ongoing threats (e.g., geopolitical relationships, inflation, industry consolidation) [47]. A highly consolidated supply chain means that a single point of failure can cause severe and widespread disruptions [42]. One example is the single forge that manufactures and refurbishes shafts for Navy surface ships and submarines [42]. The forge does not have sufficient capacity to meet demand and uses outdated equipment for which technical schools no longer train, making it difficult to obtain skilled workers [42]. Delays due to this single facility result in delays to every Navy vessel dependent on it [42]. For some critical defense sectors, new commercial entrants are disincentivized by a high barrier for entry and a weak business case [19].

As conflicts begin or change, the quantities of assets required may suddenly increase. Building surge capacity allows production to keep pace with accelerated demand. Surge capacity is currently being tested by Russia's invasion of Ukraine, where some munition inventories are being depleted at rates that far exceed replenishment while others are successfully delivered without stressing production capacity [43]. Given finite resources, a necessary trade-off must occur to ensure that DOD has the stockpiles and infrastructure required to meet future challenges while mitigating excess capacity and obsolescence [38]. Simple, granular assets such as munitions and drones can be surged more effectively after the fact, while more complex platforms require a greater degree of proactive force building.

Supply chain

		Subcategory	Indicators
	Production	**Supply chain**	**Part and material availability; stability of material costs; early identification of hard-to-obtain components; surge capacity**
		Infrastructure	Sufficient number and quality of facilities
		Production rigor	Product quality; production maturity achieved before full-rate production; production efficiency; active risk mitigation; realistic production schedule

The US is transitioning from a manufacturing and goods economy to a digital and service-based economy, resulting in lower domestic production and higher reliance on imported foreign goods [19]. One of the greatest disparities is steel, which China produces and uses in vastly greater quantities than any other nation [48]. The US is more than 50 percent import dependent on 49 nonfuel minerals, with 8 of these minerals coming from Russia and 24 coming from China [49]. The National Defense Stockpile reserves a supply of materials required for weapon production, particularly critical minerals that may be difficult to obtain during times of conflict. However, data gaps impede DOD's ability to identify the types and quantities of materials to obtain and to manage material acquisition effectively [50].

There are arguments for and against exclusive domestic sourcing. Strong reliance on adversaries presents obvious risk, but domestic production can be costly and cause delays [38]. The US has policies and legislation, such as the Buy American Act, the Berry Amendment, and the National Defense Authorization Act, that limit the procurement of foreign components.

DOD's *State of Competition Within the Defense Industrial Base* [22] identifies several vulnerable priority sectors vital to the DIB:

- **Castings and forgings.** This sector is involved in the development of almost all platforms, most subcomponents, and production equipment. Many companies take advantage of China's low labor costs and lax environmental restrictions. DOD acquisitions in this sector are often highly specialized and ordered in small quantities, providing weak commercial leverage.
- **Missiles and munitions.** This sector has a high barrier to entry given the specialized experience required, strong brand identities, costly facilities, and IP ownership. As a result, a handful of companies dominate this sector with little opportunity for new entrants, reducing competition. This can increase costs, reduce innovation, and introduce supply chain risks.
- **Energy storage and batteries.** As with castings and forgings, lower standards for worker safety and environmental effects mean that China's battery sector is stronger than that of the US. China has 82 percent of the cobalt and 93 percent of the manganese processing (components necessary to produce lithium-ion cathode material) market share. Specialty DOD batteries have low and inconsistent demand and require a high degree of skill to manufacture. Facility and production needs present high cost of entry.
- **Strategic and critical materials.** Intentional political intervention and trade actions on the part of adversary nations distort competition. Poor labor and environmental regulations also give adversary nations an advantage. The US depends heavily on foreign chemicals for weapon systems.
- **Microelectronics.** DOD is a low-volume customer with unique demands, giving it little commercial leverage. This sector has a high incentive for offshore production and a low incentive for innovation.

Example effects of supply chains on acquisitions are shown in Table 10.

Table 10. Example effects of supply chain on acquisitions

Indicator	Supporting examples
Part and material availability	**AARGM-ER:** Part delays contributed to 5 months of program delays [18].
	F/A-18E/F IRST: Subcomponent delays resulted in 5 months of program delays [18].
	MQ-4C: Affected by a shortfall on spares [4].
	NGJ MB: Circuit cards not produced at desired rate and quality [4].
	T-AO-205: Fabrication challenges resulted in a 20-month delay to lead ship delivery [4].
	SSBN-826: Material delays considered a top risk to the program [4].
	LCS packages: Supply chain issues contributed to 1-year delay [17].
	Other programs: MQ-25 [4], AMDR [4], CVN 78 [18].
Stability of material costs	**T-AO-205:** An estimated $78.2 million increase due to material cost inflation [4].
	Other programs: CVN 78 [4], AMDR [14].
Early identification of hard-to-obtain components	**FFG-62:** Identified high-efficiency super capacity chillers as a procurement risk due to high demand and addressed by establishing a second production line [17].
	SSBN-826: Began early construction on critical components to mitigate future delays [15].
Surge capacity	**Javelin and High Mobility Artillery Rocket Systems (HIMARS):** Production unable to meet demand in Ukraine while maintaining sufficient US inventory [43].
	Army Tactical Missile System: Meeting demand in Russia-Ukraine war due to production processes developed years before the start of the conflict [43].

Source: CNA.

Infrastructure

		Subcategory	Indicators
	Production	Supply chain	Part and material availability; stability of material costs; early identification of hard-to-obtain components; surge capacity
		Infrastructure	**Sufficient number and quality of facilities**
		Production rigor	Product quality; production maturity achieved before full-rate production; production efficiency; active risk mitigation; realistic production schedule

The Navy's ability to build and maintain ships is fundamentally constrained by its shipyards. The Navy currently has too few facilities, and these facilities are in poor condition. In the 1980s, the US had approximately 300 shipyards; now it has approximately 20 [51]. Over the past 50 years, 14 defense-related new-construction shipyards have closed, 3 have left the defense space, and only 1 new shipyard has opened [52]. Only one shipbuilder produces aircraft carriers, and two produce submarines [48]. The Navy contracts with 7 new-construction shipyards, which are owned by only four entities [52]. The narrow base of shipbuilders increases the potential for disruption at single points of failure, and limited domestic shipbuilding reduces the surge capacity.

Fleet maintenance is supported by the organic industrial base (OIB), which includes a network of maintenance depots, shipyards, and fleet readiness centers [19]. The OIB is responsible for many services, including platform overhauls, sustainment of older platforms not supported by the public sector, and surge capacity [19]. Yet many OIB facilities date back to WWII [19] and overwhelmingly use equipment that is past its service life [53]. Lack of modernization affects the capacity, speed, and efficiency of services [19]. Poor conditions exist at most depots, and performance has declined over the past decade [53]. Lack of modernization combined with an increased demand for new platforms has created an unfulfilled backlog of ships and submarines [42]. Outdated facilities are problematic in the private and public sectors. Narrow operating margins and inconsistent demand make it difficult for DIB companies to invest in modernization [54].

The US Navy is investing in improvements to its shipbuilding infrastructure. The Shipyard Infrastructure Optimization Program attempts to improve conditions in the Navy's four public shipyards [55]. Initiated in 2018, the project is a 20-year modernization program that currently prioritizes dry docks [55]. The project has a budget of $21 billion, although costs are projected to increase [55]. Accomplishments as of 2024 include one completed dry dock, four dry docks under construction, one scheduled to begin in 2025, and another past 50 percent design; electrical upgrades in progress at all four shipyards; delivery of new equipment; and upgrades to existing dry docks [55]. Overall, the infrastructure segment received 35.3 percent ($3.32 billion) of contracted Navy maintenance, repair, and overhaul in calendar year 2023 [56].

Tracking the progress and effectiveness of infrastructural improvements is critical. The Navy has invested $2.6 billion in the submarine supplier base but has not collected the data or performed the analysis required to track the effectiveness of these investments [57]. The Columbia-class SSBN (SSBN-826) is projected to arrive more than a year late and hundreds of millions of dollars over budget (shortcomings that current trends indicate may continue to worsen), suggesting that submarine base investments have not been sufficient [57]. Poor data management also hinders depot improvement projects [53]. Example effects of infrastructure on acquisitions are shown in Table 11.

Table 11. Example effects of infrastructure on acquisitions

Indicator	Supporting examples
Sufficient number of facilities	No examples.
Sufficient quality of facilities	**T-AO 205:** Impacted by robotic welding and steel cutting equipment failures.

Source: CNA.

Production rigor

	Subcategory	Indicators
Production	Supply chain	Part and material availability; stability of material costs; early identification of hard-to-obtain components; surge capacity
	Infrastructure	Sufficient number and quality of facilities
	Production rigor	**Product quality; production maturity achieved before full-rate production; production efficiency; active risk mitigation; realistic production schedule**

Well-developed manufacturing processes promote cost efficiencies, product quality, and reliable delivery at the desired pace and quantity.[3] Failure to achieve production maturity can result in substantial program disruptions, particularly because of insufficient product quality.

DOD acquisitions face unique challenges. DOD systems often differ considerably from standard commercial products and are ordered in relatively small quantities. As a result, manufacturing processes and systems may have to be built outside of preexisting commercial support. DOD systems are also subject to stringent requirements, which may introduce inefficiency.

Production builds from complex systems of supply and manufacturing, and acquisition programs often begin production on designs that have not reached maturity. Under these circumstances, risk cannot be avoided and active measures must be taken to manage it. Example effects of infrastructure on acquisitions are shown in Table 12.

[3] This section contains text generated by Morse Code and modified by the authors. For information regarding the machine-generated text in this report, see Appendix: AI Use Disclosure.

Table 12. Example effects of production maturity on acquisitions

Indicator	Supporting examples
Product quality	**F/A-18E/F IRST:** Quality issues, such as 20–30 percent of microelectronics failing inspection, resulted in a 10-month delivery delay [4].
	MQ-25: Improper part coating resulted in a 2-year delay [18].
	T-AO-205: Reduction gear was damaged during production, resulting in a 1-year delay and necessitating that the hull be cut for installation [4].
	SSBN-826: Weld defects were discovered after installation had begun, requiring rework and resulting in delays [14].
	AEHF satellite: Defective components caused a nearly 2-year delay and prompted retests [5].
	BMDS GMD: Faulty components were a primary driver of cost growth [5].
	Other programs: AARGM-ER [18], SSC [18], AMDR [4].
Production maturity achieved before full-rate production	**F/A-18E/F IRST:** Increased low-rate quantity without resolving manufacturing issues [4].
	MQ-25: Delays prevented the demonstration of production processes, and a high low rate production was reached before manufacturing processes were mature [18].
Production efficiency	**SSBN-826:** Block buy of Virginia- and Columbia-class submarines [7] as well as simultaneous construction of first and second platforms to increase efficiency [16].
	SSC: Procurement rate is below efficiency [4].
	AEHF satellite: Discontinuous production resulted in substantial costs [5].
	MQ-25: Contract directly with suppliers of key components to eliminate pass-through fees and combine production and spare orders [17].
	AMDR: Saw significant per-unit cost decrease when production was scaled up for installation on more platforms [18].
	NGJ MB and **F/A-18E/F IRST:** Increased procurement quantities to maintain continuous production [4, 18].
Active risk mitigation	**MQ-25:** Conducted a risk assessment after encountering numerous production issues [4].
	C-5 RERP: Conducted considerable production readiness review [5].
	SSBN-826: Conducts active assessments to identify production risks [14].
Realistic production schedule	**SSBN-826:** High-risk program due in large part to an aggressive production timeline [12].

Source: CNA.

Workforce

		Subcategory	Indicators
	Workforce	N/A	Sufficient workforce size
			Sufficient experience level
			Workplace attractiveness

Acquisition requires both high demand (e.g., software developers) and highly specialized (e.g., shipbuilders) workers. As a result, attracting and maintaining a skilled workforce large enough to support all aspects of acquisition can be difficult.

In a survey of private DIB companies conducted by NDIA, 59 percent of respondents reported that skilled-trade workers were hard or very hard to obtain, and 37 percent reported that they did not have enough skilled-trade workers to meet current production rates [36]. This labor shortage is present in the shipbuilding industry, where public shipyards were short 1,200 workers at the end of FY 2022 [19]. The US shipbuilding sector is small, producing less than 1 percent of the world's commercial ships by tonnage [48]. The overall decline in domestic shipbuilding has diminished related skills development, and niche skills, such as nuclear welding, are unlikely to be developed outside the DIB [19].

The shipbuilding industry is currently faced with a generational loss of skilled workers without ready replacements [19, 48]. Attracting new workers is difficult because of harsh physical working conditions and the lack of job security resulting from boom-bust cycles in shipbuilding and poor labor mobility [48]. Private-sector improvement initiatives and updated training programs are addressing skilled labor shortages [52]. Attracting software developers is another problem that has caused significant disruptions [16-17]. Example effects of workforce concerns on acquisitions are shown in Table 13.

Table 13. Example effects of workforce concerns on acquisitions

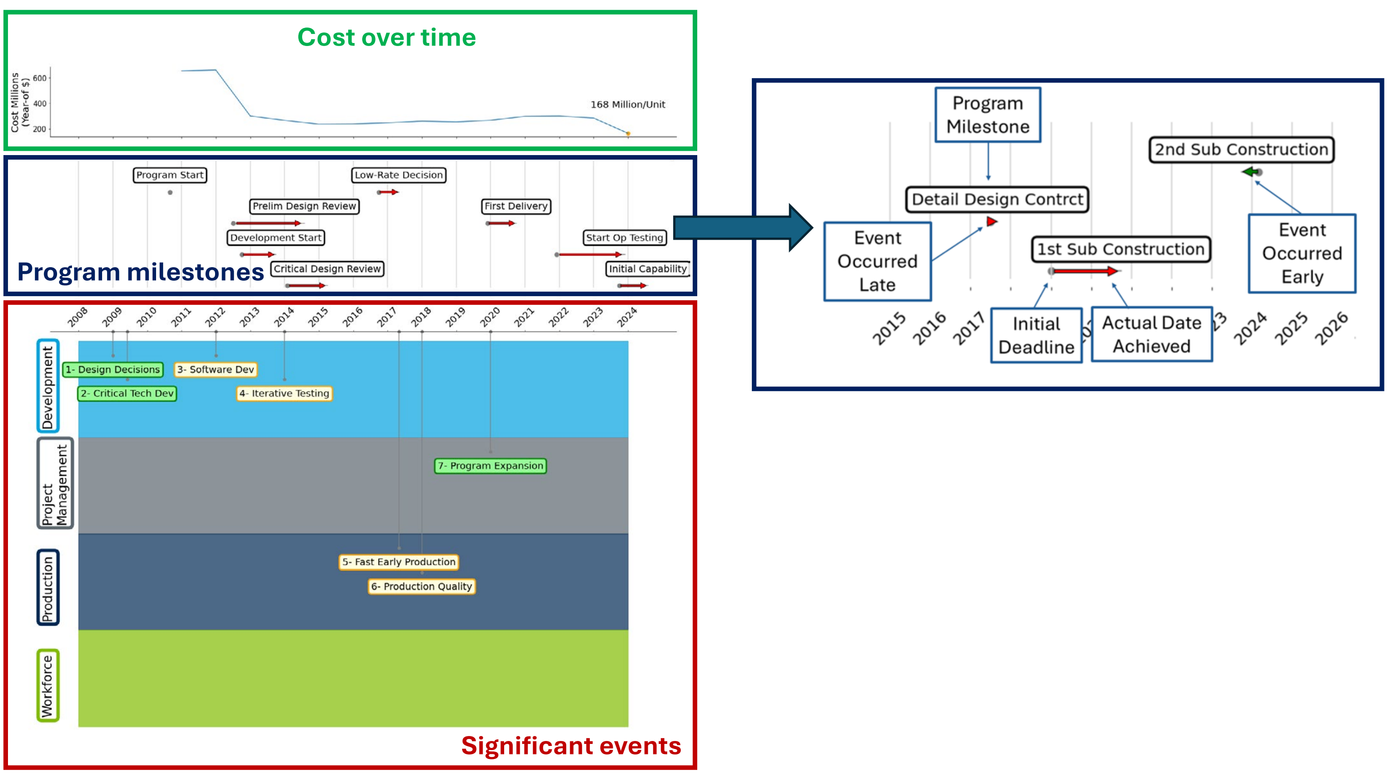
Indicator	Supporting examples
Sufficient workforce size	**T-AO-205 and CVN 78:** Working with reduced workforce because of difficulties recruiting and retaining workers and a high rate of retirement [18].
	AARGM-ER, F/A-18E/F IRST, and MQ-25: Faced software delays resulting from too few developers [16-17]. A lack of software developers is considered a top risk to the AARGM-ER program.
Sufficient experience level	**T-AO-205:** An inexperienced labor pool reduces overall efficiency; inexperience within the planning staff contributed to reduction gear delays [4].
	SSBN-826: Low proficiency in the workforce led to construction delays and necessitated greater oversight efforts [18].
	AARGM-ER: Affected by supplier learning curve [18].
Workplace attractiveness	**DDG-1000:** Ship habitability concerns prompted the loss of a contractor, possibly reducing efficiency [17].
	T-AO-205: Faced difficulty recruiting and retaining workers in the shipbuilding sector [18].
	MQ-25: Program was substantially affected by the loss of key personnel [4] and faces difficulties retaining workers [39].

Source: CNA.

Case Studies

We applied our framework to selected weapon programs to help understand what went wrong, what went right, and why. Sorting the major events provides a clear high-level "story" of each program. This story emphasizes the parts of the DIB that have the greatest effect on success and can help identify future program risks. Each program is accompanied by a visual timeline, the sections of which are illustratively described in Figure 2. In these timelines, the top section shows the estimated per-unit cost in year-of dollars, as reported in GAO's *Weapon Systems Annual Assessments*. The middle section shows the most current deadline for program milestones as well as the first reported deadline. A red arrow between the two dates indicates delay, and a green arrow indicates accomplishment ahead of the initial deadline. The lower section shows the approximate time that significant events occurred, sorted into the framework categories that best describe the events. Whether an event is green, red, or yellow indicates whether relevant indicators were qualitatively met, not met, or partially met, respectively. We examine the AMDR program first because of its relative simplicity and success, then apply the framework to the more complex and problematic Columbia program.

Figure 2. Illustrative timeline interpretation guide: Program milestones

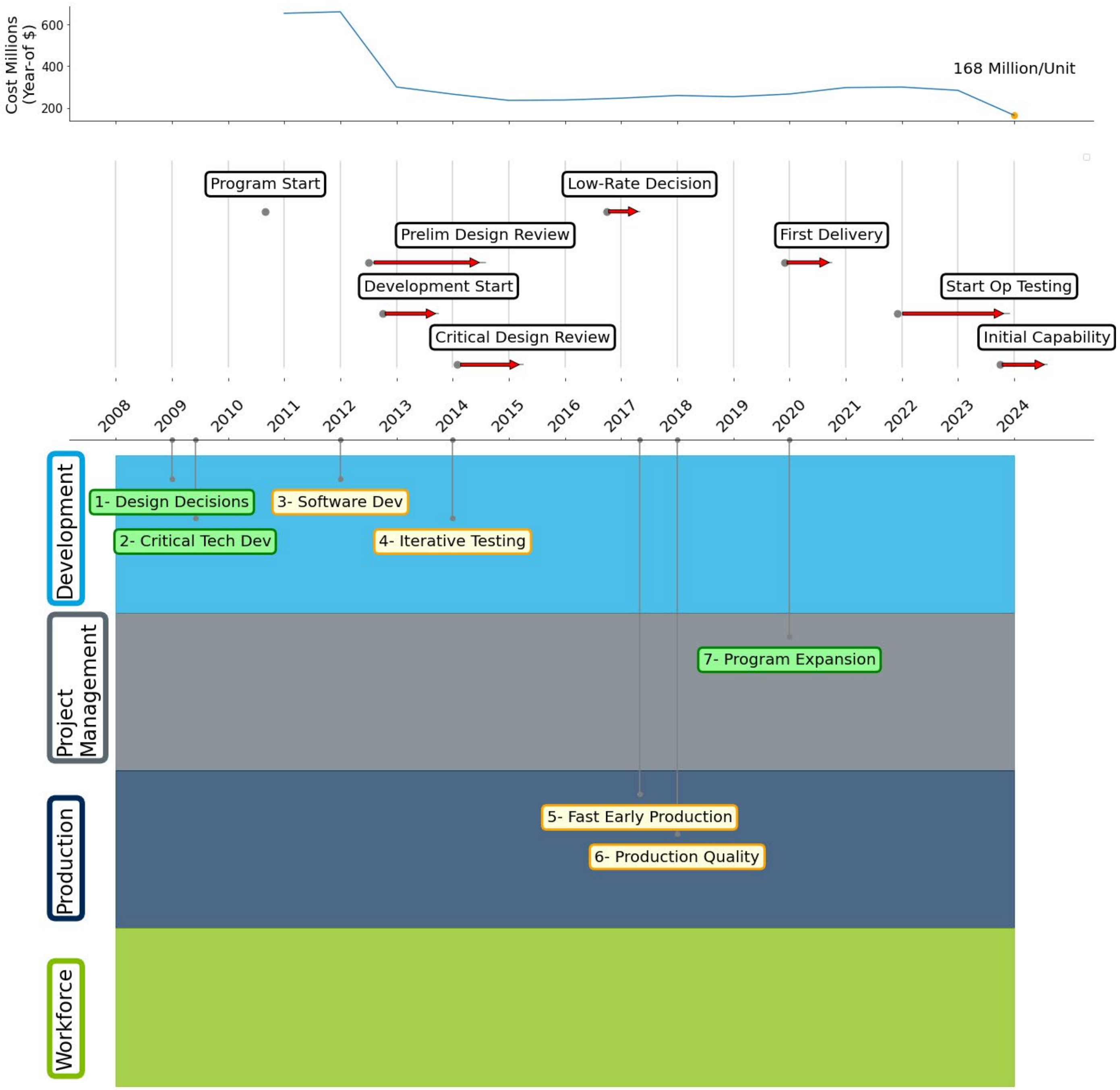


Source: CNA.

AMDR

The AMDR (or AN/SPY-6(V)1) program demonstrates success in terms of budget, capability, and, to some extent, timeliness. AMDR is unusual among weapon programs in that it has not only maintained its budget but significantly undercut initial estimates. Although the program's milestones were met later than initially planned, most of these scheduling shifts occurred early on and the program encountered only a few substantial late-stage delays. The program has thus far passed capability reviews and has realized its goal of adaptability, demonstrated by the add-on capability of the Advanced Distributed Radar (ADR) and its expansion to new platforms. Figure 3 shows a timeline of the major events, which are described in detail in the pages that follow.

Figure 3. Timeline of major events in AMDR program



Source: CNA.

Events

Event 1: Design decisions

Framework items

Category	Indicator	Met/Not met
Development	Technologies without business case off-ramped	Met
Development	Design developed on time	Met
Development	Existing tech and designs used when possible	Partially met
Project management	Interoperability	Met

AMDR was intended to support multiple ship classes with a design that is scalable and adaptable in response to evolving operational requirements [5]. To achieve greater power and efficiency in a smaller footprint, the radar incorporates gallium nitride semiconductor technology (never implemented in a radar this large) rather than gallium arsenide (demonstrated technology) [7]. The program initially planned to develop new designs for the x-ray portion of the radar [8]. During preliminary development, the program decided to incorporate an existing radar (SPQ-9B) instead and later pursue the new design as a separate add-on [8]. It was determined that a 20-foot radar would be necessary to achieve all desired functionality [7]. However, the program scaled down the size to 14 feet to meet the spatial constraints of the ship, with plans to allow for upscaling if a larger host ship is used [7]. Design drawings were 100 percent complete by the scheduled design review [11]. The completed designs remained largely stable, with the exception of the digital receiver exciter (DREX), which required redesign [12, 39].

Event 2: Critical technology development

Framework items

Category	Indicator	Met/Not met
Development	Timely testing	Met
Development	Design developed on time	Met
Development	Critical technology is mature early in design process	Met
Development	Interoperability	Met
Development	Environmentally realistic testing	Partially met
Development	Operationally realistic testing	Partially met
Program management	Appropriate penalties employed	Met
Program management	Requirements follow best practices	Partially met

Northrop Grumman, Lockheed Martin, and Raytheon were awarded fixed-price contracts to complete concept studies and critical technology demonstration plans [5-6]. The studies identified digital beamforming as the critical technology likely to take the longest to mature [5]. In accordance with new policy, potential contractors conducted competitive prototyping during a two-year development phase, followed by a limited competition for engineering and manufacturing development [5-6]. Testing led to a confident understanding of the weight, dimensions, and power requirements, which are critical to integrating the radar with its host platform (DDG-51 Flight III, designed simultaneously) [10]. The critical technologies reached near-maturity early in development and reached maturity by DOD standards before production [9, 13]. However, DOD requirements for maturity do not follow all best practices, which include demonstration in an operationally realistic environment [13]. Maturity in agreement with best practices was not achieved before production [13]. During production, the schedule was disrupted after issues were detected with the DREX [14]. Issues persisted even after redesign [15], resulting in a four-month delay to delivery and causing the system to be delivered to the lead DDG-51 Flight III platform without a complete set of DREX components [15-16].

Event 3: Software development

Framework items

Category	Indicator	Met/Not met
Development	Existing tech and designs used when possible	Met
Development	Software developed on time	Met
Development	Design free of flaws	Partially met
Program management	Interoperability	Partially met

Early in development, the program identified that it would require substantial software development efforts [8]. The program decided to use commercial off-the-shelf hardware and to take an open system development approach, including upfront requirements, architecture analysis, continuous integration, and automated testing to mitigate risk and reduce costs [8, 10, 12]. Software builds of increasing complexity were iteratively released and tested throughout the program's development, beginning with basic infrastructure, antiair warfare, and ballistic missile capabilities, and building to debris detection, advance threat discrimination, and other capabilities [10]. The software was first built for AMDR, then modified for integration with the combat system (a considerable effort) [11]. The features of the software builds were intentionally aligned with test events [11]. Core capabilities were completed prior to production [42]. However, the software experienced major deficiencies in integration with the Aegis Combat System (ACS) that caused DDG-125 not to achieve its air warfare mission during acceptance trials [18].

Event 4: Iterative testing

Framework items

Category	Indicator	Met/Not met
Development	Balanced test prioritization	Met
Development	Timely testing	Partially met
Development	Environmentally realistic testing	Partially met
Development	Operationally realistic testing	Partially met
Program management	Cross-program management	Partially met
Program management	Interoperability	Not met

A single full-size engineering development model (rather than the four-array configuration expected in the final design) was prototyped for indoor testing [10]. The full radar then underwent more realistic live ballistic missile defense and antiair and antisurface testing at a land-based test facility. However, the program did not test in an at-sea environment prior to installation [10]. Director, Operational Test and Evaluation, expressed concerns regarding the lack of robust live-fire testing and an uncrewed AMDR Aegis-equipped test ship (an effort that would require $300 to $400 million) [10]. The AMDR program developed a simulator for Aegis developers to aid integration [11]. After testing revealed AMDR-Aegis integration flaws, a newly produced array was diverted to support testing [14]. The first land-based tests integrating AMDR and ACS were conducted after production had already begun [15].

Event 5: Fast early production

Framework items

Category	Indicator	Met/Not met
Development	Timely testing	Partially met
Production	Production efficiency	Met
Production	Production maturity achieved before full-rate production	Not met

The program began production four months ahead of schedule and with lower costs than initially estimated [13]. However, the Aegis-integrated software was not scheduled to be completed until after production, precluding operational testing until after two-thirds of the radars were expected to be complete, increasing the risk of retrofitting [13]. Despite some production issues, AMDR production outpaced the production of its host ship and will likely need to be housed in storage [18].

Event 6: Production quality

Framework items

Category	Indicator	Met/Not met
Development	Timely testing	Met
Program management	Appropriate penalties employed	Met
Program management	Requirements follow best practices	Not met
Production	Active risk mitigation	Met
Production	Product quality	Not met

Although the production maturity met DOD standards, the program did not meet industry best practices and did not demonstrate statistical control even after years of production [13-14]. Adhesive was applied incorrectly to the Transmit/Receive Integrated Microwave Module, which increased costs, required reworking, and could have resulted in premature component failure [16]. After the issue was resolved, the contractor offered a warranty on the components [17]. A microelectronics issue was detected during production, but was resolved without causing substantial delay [17]. In 2022, the low-rate cost estimate increased partly because of these manufacturing issues [4]. Cracking discovered in the fabrication material delayed radar delivery briefly, and the program increased inspection rigor to ensure quality in ongoing production [4]. The program assessed the inverter modules after a burnout and implemented engineering changes and planned retrofitting to existing systems in response [4, 18]. Although the program faced quality issues, most of these defects were discovered before they could cause cascading effects and resulted in relatively small disruptions.

Event 7: Program expansion

Framework items

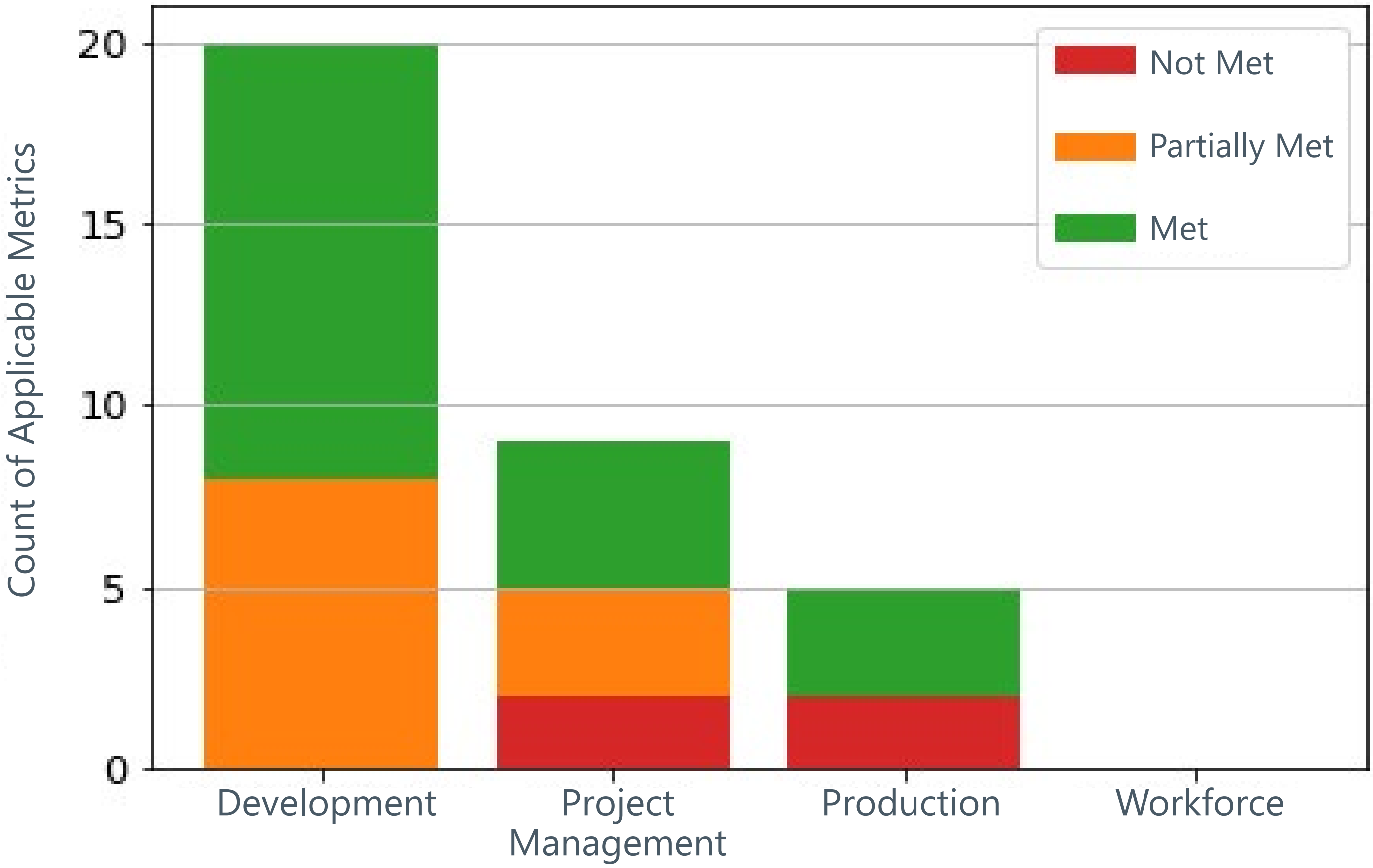
Category	Indicator	Met/Not met
Development	Existing tech and designs used when possible	Met
Development	Testing prompts redesign, and redesign prompts testing	Met
Program management	Interoperability	Met
Production	Production efficiency	Met

After production began, the program began developing ADR—a software update to supplement the program with current Navy technologies [15]. ADR is not intended to be completed until after AMDR has been fielded. In 2021, the program established the EASR to adapt AMDR for other ship classes [16]. In 2023, the number of units ordered increased from 26 to 64. The increased order nearly halved the expected unit cost by providing better pricing leverage and production efficiency [18].

Summary

Effective design practices were used for both hardware and software. For hardware, nonessential design decisions were off-ramped, rigorous testing brought critical technologies to near maturity early in development, and all designs were completed before the design review. The high software burden was considered a program risk, but iterative software rollouts scheduled around test events resulted in minimal deficiencies or delays. The production moved quickly before manufacturing processes met maturity, placing it at greater risk. However, production issues were identified and addressed as they arose. Figure 4 collects the indicators applied to all events and rolls up the outcome (Not Met, Partially Met, Met) by framework category. The counts show the number of applicable indicators, but do not necessarily represent their importance on program outcomes. The indicators suggest major program factors but are not comprehensive. For example, although we did not find any workforce-related indicators within the GAO annual assessments, workforce dynamics may nonetheless have shaped the outcomes.

Figure 4. Framework indicators met or not met in the AMDR program

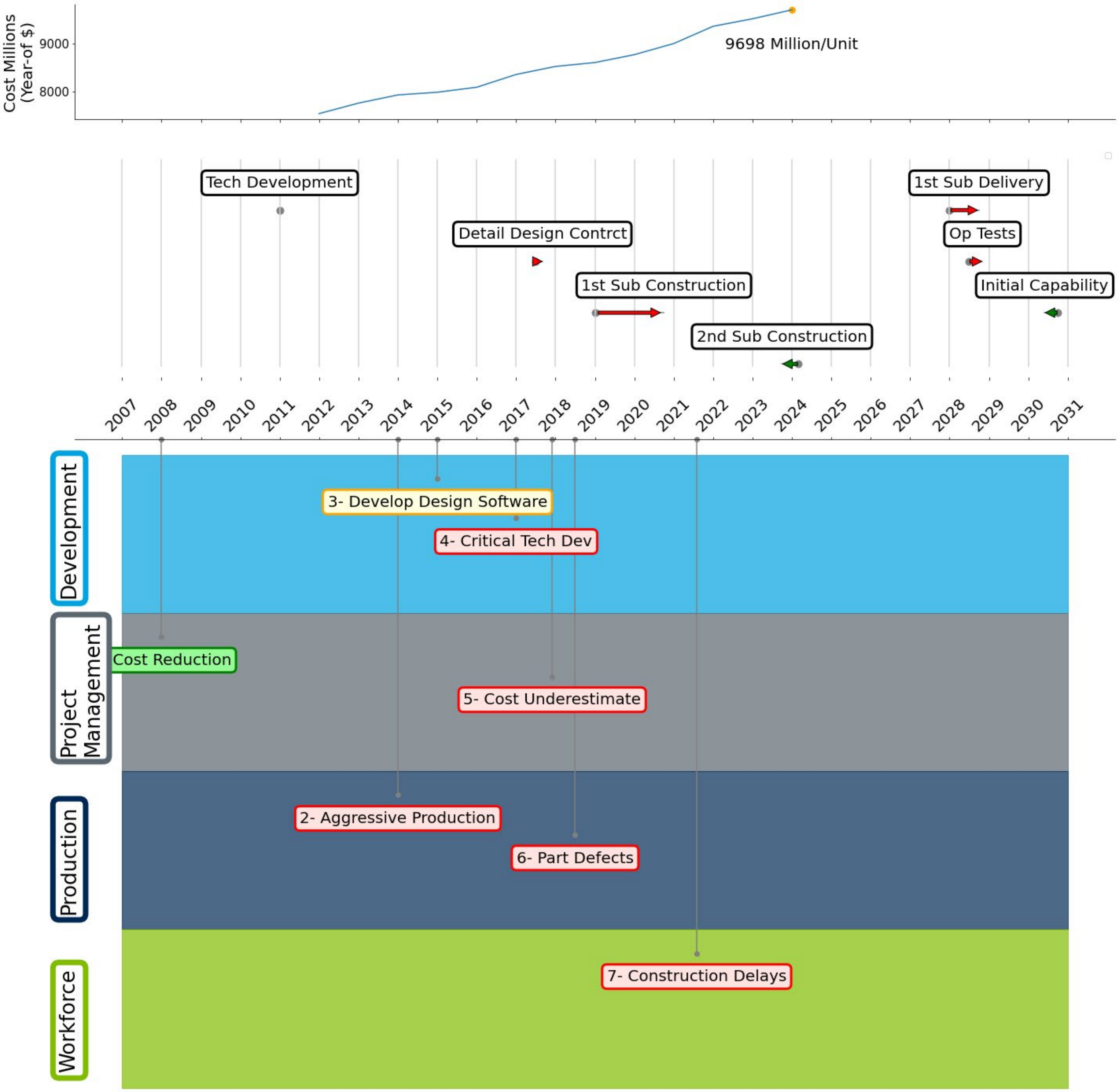


Source: CNA.

Columbia

The Columbia-class submarine program is a high-importance, high-cost, and high-complexity program. Given the challenging nature of the task, delays and cost growth may be expected to some extent. However, the program is more than a year behind schedule and billions of dollars over budget, and delays and costs are projected to increase (see Figure 5).

Figure 5. Timeline of major events in the Columbia-class submarine program



Source: CNA.

Events

Event 1: Cost reduction efforts

Framework items

Category	Indicator	Met/Not met
Program management	Interoperability	Met
Program management	Cost reduction efforts	Met
Production	Production efficiency	Met

High costs were projected to stress Navy shipbuilding budgets from 2020 to 2030, prompting cost-reduction initiatives in an effort to reduce the unit cost from $5.6 billion to $4.9 billion (in 2010 dollars) by adjusting design and production [7]. As part of these efforts, the program reduced the number of 87-inch diameter tubes from the Ohio class and prototyped a "quad pack" tube configuration for more efficient production [7].

The Navy used Virginia-class technology as much as possible, with plans to include up to 70 percent of Virginia-class parts [8, 12]. The program's Common Missile Compartment (CMC) was designed in collaboration with the UK and is shared by the Vanguard-class SSBN [5]. The Columbia program also elected to use the Trident II D-5 Strategic Weapon System [12].

Like design choices, production choices focused on cost reduction, such as pursuing a block buy of Columbia- and Virginia-class submarines [7] and leveraging common elements with the Vanguard class to obtain quantity-of-order benefits [9]. The program pursued efficient manufacturing techniques, such as robotic welding and modular construction [7].

Event 2: Aggressive production schedule

Framework items

Category	Indicator	Met/Not met
Development	Design is stable before production	Not met
Development	Critical technology is mature before production	Not met
Program management	Funding consistency	Not met
Production	Early identification of hard-to-obtain components	Met
Production	Production efficiency	Met
Production	Production maturity achieved before full-rate production	Not met
Production	Realistic production schedule	Not met

The Navy set an aggressive production timeline to match the pace of operational need. Because of fiscal constraints, the Navy delayed construction from 2018 to 2020 [8, 12]. This delay left little room for flexibility in the construction window before the first deterrent patrol scheduled for 2030 [12].

To increase production efficiency, the program modified its contract to order two submarines rather than one [16]. At the beginning of production in 2020, the program planned to build the lead platform in a span of 84 months [15]. This pace is substantially faster than that of any recent lead submarine, including during Cold War construction [13]. The planned construction cycle of the second submarine is even faster, at 80 months [4]. The acquisition cycle is scheduled to be the same as that of Virginia-class submarines, whose size and expected construction labor hours are less than half of that of the Columbia class [13]. A September 2022 GAO report [4] found that the shipbuilder's schedule does not meet best practices. In October 2022 [17], a Navy review expressed concern over the 80-month construction schedule for the second ship, citing staffing and poor work instructions as major disruptions. The Navy reported in April 2024 that the lead platform will likely be delivered 12 to 16 months late [57].

To meet an aggressive production schedule, early construction began on CMC tubes in 2014 [15]. In 2019, construction on certain elements was planned to commence two years before the Columbia class's planned authorization in 2021 [13]. Construction on the stern, bow, and mission command and control modules was planned to begin six months before production authorization [13]. Although early construction reduces the risk that critical components will be delayed, it increases the risk of rework due to design and production immaturity [13]. However, some of these efforts experienced delays and were ultimately deferred until major construction [16].

Event 3: Develop new design software

Framework items

Category	Indicator	Met/Not met
Development	Industry-standard design practices used	Met
Development	Design is stable before production	Partially met
Development	Design free of flaws	Not met

The program developed a design tool intended to speed the transition from design to construction that was validated on a representative hull section early in development [11]. However, deficiencies within the new design software delayed design delivery in 2016 [12]. The shipbuilder missed its monthly detail design goals through 2019, delaying material orders and construction progress [15]. The shipbuilder attributed the delay to flaws in the design software [15]. To overcome the tool's inefficiencies, the shipbuilder increased the design staff, which increased costs [16]. The program did not meet its goal of 83 percent detail design completion by October 2020 [16], but did achieve 100 percent 3-D functional design before beginning construction.

Event 4: Critical technology management

Framework items

Category	Indicator	Met/Not met
Development	Critical technologies mature before production	Not met
Development	Balanced test prioritization	Not met
Program management	Requirements follow best practices	Not met

In a 2017 report, GAO assessed that four technologies—the integrated power system (IPS), the propulsor/coordinated stern, the CMC, and the nuclear reactor—should have been classified as critical technologies according to best practices, but did not meet Navy requirements to be categorized as such [14]. Leading practices require "successful testing of a prototype near or at the planned operational system configuration in a realistic environment" to be considered mature [17]. The nuclear reactor reached maturity in 2018 [14]. However, none of the other technologies have reached maturity to date and were not scheduled to reach maturity until after fabrication began [15]. The propulsor/coordinated stern is not scheduled to reach maturity until after delivery [15]. By 2018, the propulsor/coordinated stern was still in detail design, and final prototypes for the propulsor/coordinated stern and IPS had not been fully tested [13]. Testing for the CMC and IPS were delayed because of test asset availability [18]. Contrary to best practices, the program was allowed to begin detail design incorporating technology that had not been demonstrated in a relevant environment [12].

Event 5: Cost underestimate

Framework items

Category	Indicator	Met/Not met
Program management	Realistic cost estimation	Not met

A GAO report cautioned that the project was likely to exceed the current cost estimate, particularly because of disruptions incurred by simultaneous development and production [13]. A later report cautioned that costs had been underestimated because of unrealistic labor-hour estimation [14]. In 2023, a third GAO report estimated costs two to three times greater than Electric Boat's best-case estimate, which does not adequately account for risks near the end of construction [18].

Event 6: Part defects

Framework items

Category	Indicator	Met/Not met
Development	Design is stable before production	Not met
Program management	Application of sector-appropriate oversight	Not met
Program management	Sufficient contractor capacity	Not met
Production	Product quality	Not met
Production	Part and material availability	Not met
Workforce	Sufficient experience level	Not met

Manufacturing defects in the first production-representative motor for the IPS delayed the prototype delivery from 2017 to 2019 [15]. To recover the schedule, the program began to test the motor and update production designs simultaneously, placing the production maturity at risk should further deficiencies be discovered [14].

Shipbuilders found significant weld defects in CMC missile tubes originating from one of three suppliers [14]. The defects were discovered after seven tubes had already been delivered and installation had begun, necessitating rework [14]. The stated cause of the defects was inexperienced welders and inspectors [14]. The quality issues and resulting delays were identified as a risk to on-time delivery for the lead platform [14]. The CMC is a critical technology according to best practices but was not identified as such by Navy requirements (see "Event 4: Critical technology management"). The discovery prompted a quality assurance review that revealed weld defects throughout the industrial base, attributed to increased demand and reduced oversight [15]. As a result, the Navy increased oversight on high-risk suppliers and invested in quality improvement [15]. As of 2020, the CMC schedule was still recovering from the disruptions [16].

Event 7: Construction delays

Framework items

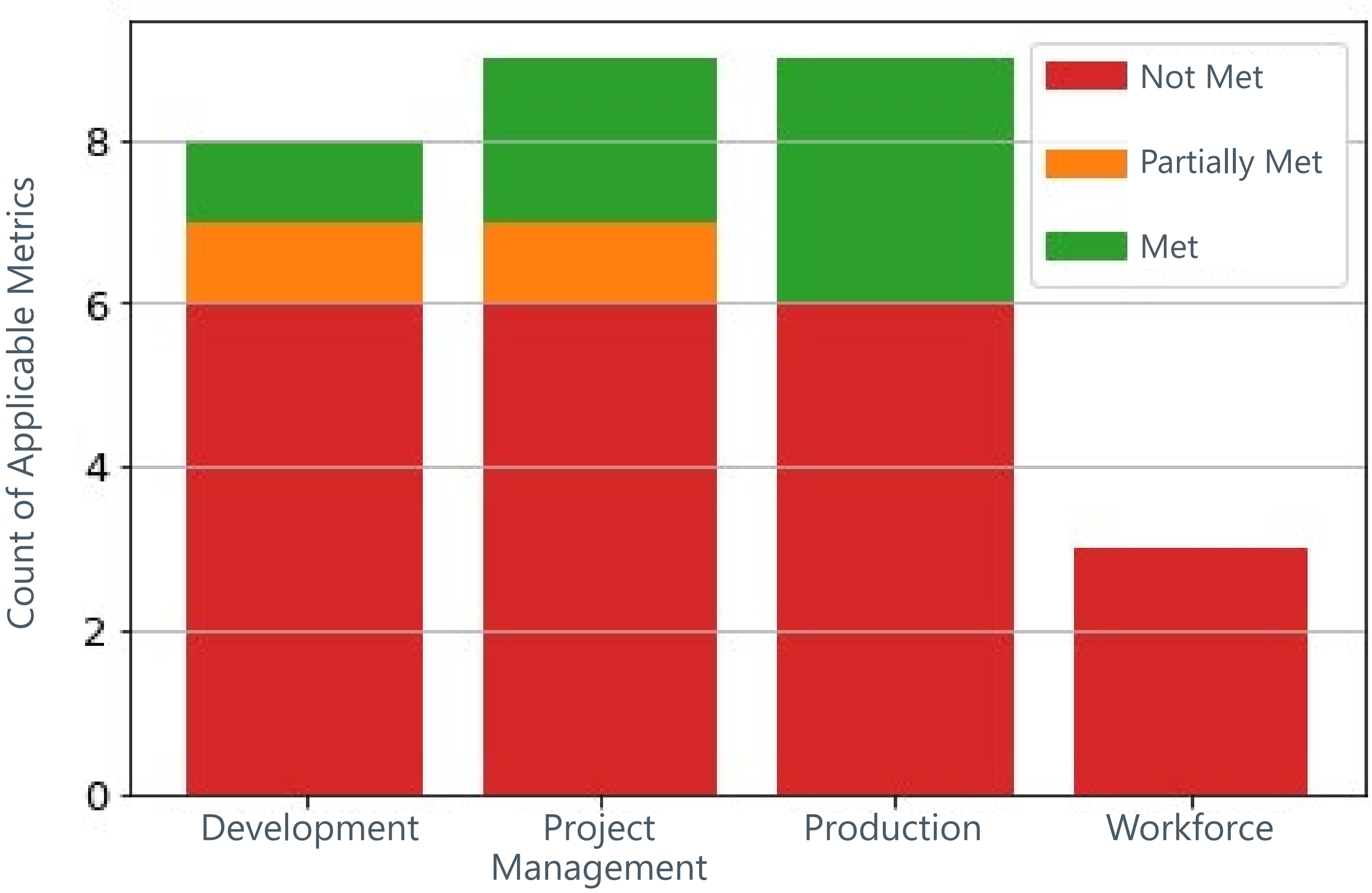
Category	Indicator	Met/Not met
Program management	Cross-program management	Partially met
Program management	Application of sector-appropriate oversight	Not met
Production	Product quality	Not met
Production	Part and material availability	Not met
Workforce	Sufficient workforce size	Not met
Workforce	Sufficient experience level	Not met

The shipbuilder reported construction delays caused by delays in materials delivery, and rework due to errors and quality issues, among other problems [17]. A small, inexperienced workforce requires more detailed instructions than an experienced workforce to complete quality construction quickly [18]. Failure to provide timely, detailed work instructions contributed to delays and may cause additional quality issues and reworking [18]. The Navy identified the workforce as a risk to meeting the production schedule and shipbuilders are attempting to increase hiring [4]. Delays were mitigated by prioritizing Columbia over Virginia work when allocating resources, including staff [17].

Summary

The program began with several effective design choices that shared elements across national and international submarine programs and made concerted efforts to reduce costs. However, the disconnect between DOD policy and best practices caused several key technologies not to be categorized as critical technologies. Even after the start of construction, several of these technologies have not been realistically tested, placing the program at risk. Perhaps the greatest risk to the program is the fast-paced production schedule, which was shortened further because of budget instability. The aggressive schedule means that any disruptions can have cascading effects, and that design, production, and testing are occurring simultaneously in an unstable manner. The pace of production is poorly supported by an inexperienced workforce and an overburdened supply chain. Hundreds of millions of dollars were invested in supplementing the submarine-sector DIB [57]. However, these efforts were not well tracked and whether they have been successful is unclear [57]. The program is expected to face more cost growth and disruptions. Figure 6 collects the indicators applied to all events and rolls up the outcome (Not Met, Partially Met, Met) by framework category. The counts show the number of applicable indicators but do not necessarily represent their importance on program outcomes.

Figure 6. Framework criteria met or not met in the Columbia submarine program



Source: CNA.

Conclusions

The framework we developed is intended to describe in simple terms the most common factors that significantly affect a program's ability to deliver weapons or platforms on time and within budget.[4] The US DIB depends on interactions between DOD entities, domestic commercial entities, and foreign entities to plan and execute acquisitions. Some aspects of the DIB, such as workforce dynamics and multinational supply chains, are external to DOD. Other aspects, such as design decisions, data collection, and organizational structure, are within DOD's purview.

External factors can cause immense program disruptions. For example, one of the greatest risks to the Columbia program is a small and unskilled workforce—a problem difficult for DOD to fix. This problem has been exacerbated by program management, which issued work instructions with insufficient quality and timeliness, causing confusion, errors, and delays among an inexperienced workforce. Building up a niche labor sector or issuing high-quality work instructions both help to address the same problem, but one is easier and cheaper to achieve.

Many issues arise from the complex systems of contractors, supply chains, and workforce dynamics that are difficult for DOD to control. However, the ability of an acquisition program to meet expectations is also strongly influenced by intra-organizational action DOD does directly control. Internal decisions—for example, those related to design, testing, and management practices—have an immense effect on a program's outcome. Internal factors affect success from the beginning to the end of the program life cycle, and mistakes early in the process can cause compounding problems for decades. Many parties affect the health of the larger industrial base, but only DOD can fix its own organizational problems. To improve acquisitions and the US DIB, DOD must look inward.

[4] This section contains text generated by OPNAV GPT and modified by the authors. For information regarding the machine-generated text in this report, see Appendix: AI Use Disclosure.

Appendix: AI Use Disclosure

We used Microsoft Copilot, OPNAV GPT, CNA's Morse Code (derived from ChatGPT 4.0), and ChatGPT to aid our work in several ways. During the literature review, we generated high-level summaries to help identify topics on which to focus our research. We also generated lists of possible literature sources for various topics, then used these sources to inform our work.

In certain sections of this report, human-generated text was used to create machine-generated text, portions of which were then re-edited and incorporated. All such sections are identified by footnotes. The machine-generated text used to inform these sections is shown below.

Machine-generated text

Executive summary

From OPNAV GPT:

The document offers a detailed examination of the challenges faced by the Defense Industrial Base (DIB) in delivering acquisition programs on time and within budget. It utilizes a framework focusing on Development, Program Management, Production, and Workforce to analyze recurring issues across various weapon programs.

Key Challenges:

1. **Workforce Shortages:** Difficulty in recruiting and retaining skilled workers has significantly impacted program timelines and costs. For instance, T-AO 205 and CVN 78 experienced workforce reductions due to retirement rates and recruitment challenges.
2. **Software Delays:** Programs like AARGM-ER, IRST, and MQ-25 encountered delays due to insufficient software developers.
3. **Design Quality:** Issues such as design flaws in systems like EMALS and AAG for CVN 78 led to cost increases. Flaws in design software also caused delays in programs like Columbia.

Program Management:

- Inadequate oversight and unrealistic cost estimations have been consistent issues. The GAO highlighted that many projects underestimated costs, leading to overruns.
- The failure to provide timely, detailed work instructions has caused delays and rework in several programs.

Production Risks:

- Immature technologies entering production phases have often resulted in costly redesigns and delays. For example, the Columbia program faced significant weld defects discovered post-installation.
- Material cost inflation also posed challenges; T-AO 205 saw substantial cost increases due to material price hikes.

Supply Chain Issues:

- Dependency on foreign suppliers for critical components poses risks. The US is heavily reliant on imports for essential materials like cobalt and manganese used in defense manufacturing.

Recommendations

1. **Enhance Workforce Development:** Implement targeted training programs to build a skilled labor force capable of meeting DIB needs.
2. **Strengthen Software Capabilities:** Invest in attracting more software developers to reduce delays associated with software integration.
3. **Improve Design Practices:** Adopt modern design technologies such as digital engineering techniques to enhance efficiency and reduce errors.
4. **Implement Robust Oversight Mechanisms:** Strengthen oversight practices to ensure realistic cost estimations and effective contractor management.

Testing rigor

From Morse Code:

To accurately assess performance, **tests must capture operational and environmental realism** and be completed with suitable rigor. Realism can be difficult to achieve due to the costs and coordination involved. However, testing that does not accurately represent how a system will be used may allow flaws to be overlooked. **Substandard testing can lead to problems later in development or operation that increase costs and reduce effectiveness**.

Importance of Realistic Testing

Operational and environmental realism in testing is crucial for the US defense industrial base for several reasons:

1. **Identification of Potential Flaws:** Realistic testing environments help identify potential flaws in systems that might not be apparent in controlled or ideal conditions. This ensures that the final product performs reliably under actual operational conditions.
2. **Cost Efficiency:** While achieving realism in tests can be expensive, it is often more cost-effective in the long run. Identifying and rectifying flaws during the testing phase is generally less costly than addressing issues that arise during deployment or operation.
3. **Enhanced Effectiveness:** Systems that are rigorously tested under realistic conditions are more likely to perform effectively in real-world scenarios. This enhances the overall effectiveness and reliability of defense systems.

Challenges in Achieving Realism

Achieving operational and environmental realism in testing presents several challenges:

1. **High Costs:** Creating realistic testing environments can be prohibitively expensive. This includes costs associated with materials, labor, and the replication of real-world conditions.
2. **Coordination and Logistics:** Realistic testing often requires extensive coordination and logistics. This can involve multiple stakeholders, including different branches of the military, defense contractors, and regulatory bodies.
3. **Technological Limitations:** Some aspects of operational environments may be difficult to replicate accurately due to technological limitations. This can include factors such as weather conditions, terrain variability, and the presence of adversarial forces.

Consequences of Substandard Testing

Substandard testing can have significant negative impacts on the US defense industrial base:

1. **Increased Development Costs:** Flaws that are

not identified during initial testing phases can lead to increased costs during later stages of development. This includes costs associated with redesign, retesting, and potential delays in deployment.

2. **Operational Failures:** Systems that have not been rigorously tested are more likely to fail during actual operations. This can compromise mission success and potentially endanger lives.

3. **Reduced Confidence:** Substandard testing can erode confidence in defense systems among military personnel and stakeholders. This can impact the overall perception of the defense industrial base's capability to deliver reliable and effective solutions.

Strategies to Improve Test Quality

To address these challenges and improve test quality, several strategies can be employed:

1. **Investment in Testing Infrastructure:** Investing in advanced testing facilities and technologies can help create more realistic testing environments. This includes simulation technologies, advanced sensors, and automated testing systems.

2. **Collaboration and Partnerships:** Enhancing collaboration between defense contractors, military branches, and regulatory bodies can improve coordination and logistics. This can lead to more efficient and effective testing processes.

3. **Continuous Improvement:** Implementing a culture of continuous improvement in testing methodologies can help identify and address gaps in test quality. This includes regular reviews, feedback loops, and the incorporation of lessons learned from previous testing cycles.

By addressing these challenges and implementing effective strategies, the US defense industrial base can ensure that its systems are rigorously tested and capable of performing reliably in real-world scenarios.

Timely testing is a critical component in the development process of defense systems. **Early detection** of issues can significantly reduce the cost and time needed to address them, ensuring that the final product meets the required standards and operational readiness.

Early Development Phase

During the **early development phase**, testing allows for the identification of potential flaws in design and functionality. Addressing these issues early can prevent costly redesigns and production delays. This phase often includes:

- **Conceptual Testing:** Verifying the feasibility of new technologies and concepts.
- **Prototype Testing:** Evaluating early models to identify design flaws and performance issues.

Design Phase

If problems are identified during the **design phase**, the impact can be more substantial. Adjustments at this stage may require significant rework of the design, which can delay production schedules and increase costs. Key activities include:

- **Detailed Design Reviews:** Ensuring all aspects of the design meet the specified requirements.
- **Simulation and Modeling:** Using advanced tools to predict how the system will perform under various conditions.

Production Phase

Discovering issues during the **production phase** can be even more detrimental. At this stage, changes can lead to:

- **Production Line Interruptions:** Halting the manufacturing process to implement fixes.
- **Increased Costs:** Higher expenses due to re-tooling and additional quality control measures.

Post-Delivery Phase

Identifying problems **after delivery** can have severe consequences, including:

- **Operational Failures:** Compromising the safety and effectiveness of military operations.
- **Expensive Recalls and Retrofits:** Implementing fixes in fielded systems, which is both time-consuming and costly.
- **Reputation Damage:** Eroding trust in the defense contractor's ability to deliver reliable and effective systems.

Strategic Importance

For the **US defense industrial base**, timely testing is not just a matter of efficiency but a strategic imperative. The ability to deliver high-quality, reliable defense systems on time is crucial for maintaining national security and technological superiority. Key benefits include:

- **Enhanced Readiness:** Ensuring that military forces have access to the latest and most effective technology without delays.
- **Cost Savings:** Reducing the overall lifecycle costs of defense systems by preventing late-stage modifications.
- **Competitive Advantage:** Maintaining a leading edge in defense technology by streamlining the development and deployment process.

Conclusion

In summary, **timely testing** is essential for the US defense industrial base to ensure the delivery of high-quality, reliable defense systems. By identifying and addressing issues early in the development process, the defense industry can avoid costly delays and maintain its strategic advantage.

Production maturity

From Morse Code:

Production maturity refers to the ability of manufacturing processes to consistently produce parts and systems that meet quality standards at the required scale. Achieving production maturity is critical for the US defense industrial base for several reasons:

1. **Reliability and Performance:** Defense systems must perform reliably under various conditions. **High production maturity ensures that components and systems meet stringent quality and performance standards**, reducing the risk of failures in the field.
2. **Cost Efficiency:** Mature production processes are typically more cost-effective due to optimized workflows, reduced waste, and economies of scale. **Cost overruns and budget constraints are significant concerns in defense procurement**, and achieving production maturity helps mitigate these issues.
3. **Timely Delivery:** Defense programs often have strict timelines to meet operational requirements. **Delays in production can have cascading effects on deployment schedules and overall mission readiness**. Production maturity ensures that manufacturers can meet delivery deadlines consistently.

Challenges of Achieving Production Maturity

Several challenges can impede the achievement of production maturity in the defense sector:

1. **Complexity of Systems:** Defense systems

are often highly complex, involving advanced technologies and intricate components. **Ensuring quality and consistency in such complex systems requires sophisticated manufacturing processes and rigorous quality control**.

2. **Supply Chain Dependencies:** The defense industrial base relies on a network of suppliers and subcontractors. **Any disruptions or quality issues within the supply chain can impact the overall production maturity** of the final product.

3. **Regulatory Compliance:** Defense manufacturing must comply with stringent regulatory standards and certifications. **Navigating these regulations can be challenging and time-consuming**, affecting production timelines and quality.

4. **Technological Advancements:** The rapid pace of technological advancements means that defense systems are continually evolving. **Manufacturers must adapt their processes to incorporate new technologies while maintaining production maturity**.

Strategies to Enhance Production Maturity

To address these challenges and enhance production maturity, several strategies can be employed:

1. **Investing in Advanced Manufacturing Technologies: Adopting technologies such as additive manufacturing, robotics, and automation can improve precision, reduce errors, and increase production efficiency.**

2. **Implementing Robust Quality Control Systems: Establishing comprehensive quality control measures throughout the production process ensures that all components meet the required standards.** This includes regular inspections, testing, and validation procedures.

3. **Strengthening Supplier Relationships: Building strong partnerships with suppliers and fostering open communication can help mitigate supply chain risks.** Collaborative efforts to improve quality and reliability across the supply chain are essential.

4. **Continuous Improvement and Training: Encouraging a culture of continuous improvement and providing ongoing training for the workforce can enhance production capabilities.** Staying updated with best practices and industry standards is crucial.

5. **Risk Management and Contingency Planning: Developing robust risk management strategies and contingency plans can help address potential disruptions**. This includes identifying critical risks, monitoring potential issues, and having backup plans in place.

Conclusion

Achieving production maturity is essential for the US defense industrial base to deliver high-quality, reliable, and cost-effective defense systems. By addressing the challenges and implementing effective strategies, manufacturers can ensure that they meet the demanding requirements of defense programs, ultimately contributing to national security and operational readiness.

By focusing on these aspects, the US defense industrial base can enhance its production maturity, ensuring that it can meet the needs of the military with high-quality, reliable, and timely products.

Conclusions

From OPNAV GPT:

The document offers a detailed examination of the challenges faced by the Defense Industrial Base (DIB) in delivering acquisition programs on time and within budget. It utilizes a framework focusing on

Development, Program Management, Production, and Workforce to analyze recurring issues across various weapon programs. Key challenges identified include workforce shortages, difficulty in recruiting and retaining skilled workers which significantly impacted program timelines and costs. For instance, T-AO 205 and CVN 78 experienced workforce reductions due to retirement rates and recruitment challenges. Additionally, software delays were prevalent with programs like AARGM-ER, IRST, and MQ-25 encountering delays due to insufficient software developers. Design quality issues such as design flaws in systems like EMALS and AAG for CVN 78 led to cost increases, while flaws in design software caused delays in programs like Columbia.

Program management practices were found inadequate with unrealistic cost estimations being a consistent issue. The GAO highlighted that many projects underestimated costs leading to overruns, and failure to provide timely, detailed work instructions caused delays and rework in several programs. Production risks included immature technologies entering production phases resulting in costly redesigns and delays as seen in the Columbia program that faced significant weld defects discovered post-installation. Material cost inflation also posed challenges; T-AO 205 saw substantial cost increases due to material price hikes.

Supply chain issues further complicated matters with dependency on foreign suppliers for critical components posing risks. The US is heavily reliant on imports for essential materials like cobalt and manganese used in defense manufacturing. To address these challenges, several recommendations have been made: Enhance workforce development by implementing targeted training programs to build a skilled labor force capable of meeting DIB needs; Strengthen software capabilities by investing in attracting more software developers to reduce delays associated with software integration; Improve design practices by adopting modern design technologies such as digital engineering techniques to enhance efficiency and reduce errors; Implement robust oversight mechanisms by strengthening oversight practices to ensure realistic cost estimations and effective contractor management.

In conclusion, while external factors such as workforce dynamics are challenging for the DOD to control, internal improvements in program management practices can significantly enhance acquisition outcomes.

Figures

Tables

Abbreviations

AAG	Advanced Arresting Gear
AARGM	Advanced Anti-Radiation Guided Missile
ABL	airborne laser
ACS	Aegis Combat System
ADR	Advanced Distributed Radar
AEHF	advanced extremely high frequency
AGM	air-to-ground missile
AMDR	Air and Missile Defense Radar
BMD	ballistic missile defense
BMDS	ballistic missile defense system
CDD	capability development document
CMC	Common Missile Compartment
CR	continuing resolution
CVN	nuclear-powered aircraft carrier
DDG	guided missile destroyer
DIB	defense industrial base
DOD	Department of Defense
DREX	digital receiver exciter
EASR	Enterprise Air Surveillance Radar
EMALS	Electromagnetic Aircraft Launch System
ER	extended range
FTF	Flexible Target Family
FY	fiscal year
GAO	US Government Accountability Office
GMD	ground-based midcourse defense
HARM	High-Speed Anti-Radiation Missile
HIMARS	High Mobility Artillery Rocket System
IP	intellectual property
IPS	integrated power system
IRST	infrared search and track
LCS	Littoral Combat Ship
MB	Mid-Band
NDIA	National Defense Industrial Association
NGJ	Next Generation Jammer
OIB	organic industrial base

RERP	Reliability Enhancement and Re-engineering Program
SSBN	nuclear-powered ballistic-missile submarine
T-AO	fleet replenishment oiler, auxiliary ship
THAAD	Terminal High-Altitude Area Defense
VFI	vendor-furnished information

References

[1] MITRE. 2024. *Achieving True Logistics Resiliency Within the United States*. https://www.mitre.org/sites/default/files/2024-08/PR-24-01820-9-Achieving-True-Logistics-Resiliency-Within-United-States.pdf.

[2] Congressional Budget Office. 2024. *An Analysis of the Navy's 2025 Shipbuilding Plan*. https://www.cbo.gov/publication/60732.

[3] US Government Accountability Office. 2024. *Navy Shipbuilding: Increased Use of Leading Design Practices Could Improve Timeliness of Deliveries*. https://www.gao.gov/products/gao-24-105503.

[4] US Government Accountability Office. 2023. *Weapon Systems Annual Assessment: Programs are not Consistently Implementing Practices that can Help Accelerate Acquisitions*. https://www.gao.gov/products/gao-23-106059.

[5] US Government Accountability Office. 2010. *Defense Acquisitions: Assessments of Selected Weapon Programs*.

[6] US Government Accountability Office. 2011. *Defense Acquisitions: Assessments of Selected Weapon Programs*.

[7] US Government Accountability Office. 2012. *Defense Acquisitions: Assessments of Selected Weapon Programs*.

[8] US Government Accountability Office. 2013. *Defense Acquisitions: Assessments of Selected Weapon Programs*.

[9] US Government Accountability Office. 2014. *Defense Acquisitions: Assessments of Selected Weapon Programs*.

[10] US Government Accountability Office. 2015. *Defense Acquisitions: Assessments of Selected Weapon Programs*.

[11] US Government Accountability Office. 2016. *Defense Acquisitions: Assessments of Selected Weapon Programs*.

[12] US Government Accountability Office. 2017. *Defense Acquisitions: Assessments of Selected Weapon Programs*.

[13] US Government Accountability Office. 2018. *Weapon Systems Annual Assessment: Knowledge Gaps Pose Risks to Sustaining Recent Positive Trends*. https://www.gao.gov/products/gao-18-360sp.

[14] US Government Accountability Office. 2019. *Weapon Systems Annual Assessment: Limited use of Knowledge-Based Practices Continues to Undercut DOD's Investments*. https://www.gao.gov/products/gao-19-336sp.

[15] US Government Accountability Office. 2020. *Defense Acquisitions Annual Assessment: Drive to Deliver Capabilities Faster Increases Importance of Program Knowledge and Consistent Data Oversight*. https://www.gao.gov/products/gao-20-439.

[16] US Government Accountability Office. 2021. *Weapon Systems Annual Assessment: Updated Program Oversight Aproach Needed*. https://www.gao.gov/products/gao-21-222.

[17] US Government Accountability Office. 2022. *Weapon Systems Annual Assessment: Challenges to Fielding Capabilities Faster Persists*. https://www.gao.gov/products/gao-22-105230.

[18] US Government Accountability Office. 2024. *Weapon Systems Annual Assessment: DOD Is Not Yet Well-Positioned to Field Systems with Speed*. https://www.gao.gov/products/gao-24-106831.

[19] Department of Defense. 2023. *National Defense Industrial Strategy*. https://www.businessdefense.gov/docs/ndis/2023-NDIS.pdf.

[20] Panella, Chris. 2024. "These Big Shipyards Are China's Shipbuilding Power Players and Are Cranking Out New Warships at a Breakneck Pace." Business Insider. Sept. 21. https://www.businessinsider.com/chinas-shipbuilding-power-players-making-warships-at-a-rapid-pace-2024-9.

[21] ACC Public Affairs. 2022. "ACC Federal Laboratory Flies Combat Apps on F-22 with New Open Software Stack." Air Combat Command. Aug. 29. https://www.acc.af.mil/News/Article/3143143/acc-federal-laboratory-flies-combat-apps-on-f-22-with-new-open-software-stack/.

[22] Office of the Under Secretary of Defense for Acquisition and Sustainment. 2022. *State of Competition Within the Defense Industrial Base*. https://media.defense.gov/2022/feb/15/2002939087/-1/-1/1/state-of-competition-within-the-defense-industrial-base.pdf.

[23] Clayton, Brittany, Obaid Younossi, Sarah W. Denton, Hilary Reininger, Angela Yun, David M. Adamson, Thao Liz Nguyen, Jonathan Roberts, Padmaja Vedula, Thomas Light, Augustine Bravo, Oluwatimilehin Sotubo, and Mohammad Ahmadi. 2024. *The Impact of Digital Engineering on Defense Acquisition and the Supply Chain: Insights from an Industry Survey*. RAND. RRA2333-2. https://www.rand.org/pubs/research_reports/RRA2333-2.html.

[24] MITRE. 2024. *Recommendations to Modernize Archaic and Insecure Legacy Systems*. https://www.mitre.org/news-insights/publication/recommendations-modernize-archaic-and-insecure-legacy-systems.

[25] Gonzales, Daniel, Sarah Harting, Mary Kate Adgie, Julia Brackup, Lindsey Polley, and Karlyn D. Stanley. 2020. *Unclassified and Secure: A Defense Industrial Base Cyber Protection Program for Unclassified Defense Networks*. RAND. RR4227. https://www.rand.org/pubs/research_reports/RR4227.html.

[26] US Government Accountability Office. 2022. *Leading Practices: Agency Acquisition Policies Could Better Implement Key Product Development Principles*. https://www.gao.gov/products/gao-22-104513.

[27] Martin, Tim. 2024. "High Price of Red Sea Shootdowns Speeds Navy's Pursuit of 'Cost-Effective' Solutions." Breaking Defense. May 15. https://breakingdefense.com/2024/05/high-price-of-red-sea-shootdowns-speeds-navys-pursuit-of-cost-effective-solutions/.

[28] Baker, Sinead. 2025. "The Ukraine War Shows Why the West Needs Cheap, Throwaway Weapons It Can Make Quickly, Not Just the Expensive Stuff." Business Insider. Feb. 21. https://www.businessinsider.com/the-west-needs-more-cheap-weapons-counter-russia-and-china-2025-2.

[29] O'Hanlon, Michael, and Alejandra Rocha. 2024. "Strengthening America's Defense Industrial Base." June 20. https://www.brookings.edu/articles/strengthening-americas-defense-industrial-base/.

[30] Department of Defense. 2023. *Small Business Strategy*. https://media.defense.gov/2023/jan/26/2003150429/-1/-1/0/small-business-strategy.pdf.

[31] National Defense Industrial Association. 2023. *Vital Signs 2023: Posturing the US Industrial Base for Great Power Competition*. https://www.ndia.org/-/media/sites/ndia/policy/vital-signs/2023/ndia_vitalsigns2023_final_v3.pdf.

[32] Walker, Robert S., F. Whitten Peters, Buzz Aldrin, John Hamre, Edward Bolen, William Schneider, Thomas Buffenbarger, Robert Stevens, John Douglass, Neil deGrasse Tyson, Tillie Fowler, and Heidi Wood. 2002. *Final Report of the Commission on the Future of the United States Aerospace Industry: Anyone, Anything, Anywhere, Anytime*. https://www.nasa.gov/wp-content/uploads/2024/01/aerocommissionfinalreport.pdf.

[33] Mehta, Aaron. 2016. "30 Years: William Perry—Reshaping the Industry." *Defense News*. Oct. 25. https://www.defensenews.com/30th-annivesary/2016/10/25/30-years-william-perry-reshaping-the-industry/.

[34] Albon, Courtney. 2024. "Anduril Lands $250 Million Pentagon Contract for Drone Defense System." *Defense News*. Oct. 8. https://www.defensenews.com/unmanned/2024/10/08/anduril-lands-250-million-pentagon-contract-for-drone-defense-system/.

[35] Blinde, Loren. 2023. "Lockheed Martin Invests in HawkEye 360." *Intelligence Community News*. Oct. 23. https://intelligencecommunitynews.com/lockheed-martin-invests-in-hawkeye-360/.

[36] National Defense Industrial Association. 2024. *Vital Signs 2024*: *The Health and Readiness of the Defense Industrial Base*. https://www.ndia.org/-/media/sites/ndia/policy/vital-signs/2024/2024_vital_signs_final.pdf.

[37] Day, David. 2012. "The Limits of Monopsony Pricing Power in the Markets for Defense Goods." In *The Limits of Competition in Defense Acquisition Defense Acquisition University Research Symposium,* Sept. 2012. https://apps.dtic.mil/sti/citations/ADA580012.

[38] Nicastro, Luke A. 2023. *The US Defense Industrial Base: Background and Issues for Congress*. Congressional Research Service. R47751 (updated Sept. 23, 2024). https://sgp.fas.org/crs/natsec/R47751.pdf.

[39] US Government Accountability Office. 2021. *Weapon System Requirements: Joint Staff Lacks Reliable Data on the Effectiveness of Its Revised Joint Approval Process*. https://www.gao.gov/products/gao-22-104432.

[40] MITRE. 2024. *Motivating a Supply Chain Enterprise Approach to Protect the Defense Industrial Base*. https://www.mitre.org/news-insights/publication/motivating-supply-chain-enterprise-approach-protect-defense-industrial.

[41] Monroe, Raymond. 2024. "Castings and Forgings Struggle with the National Defense Industrial Strategy." National Defense Industrial Association. https://www.ndia.org/-/media/sites/ndia/meetings-and-events/2024/5/419a-may-manufacturing/speaker-presentations/6-raymond-monroendia-512024.pdf.

[42] Department of Defense. 2018. *Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States*. https://media.defense.gov/2018/Oct/05/2002048904/-1/-1/1/ASSESSING-AND-STRENGTHENING-THE-MANUFACTURING-AND-DEFENSE-INDUSTRIAL-BASE-AND-SUPPLY-CHAIN-RESILIENCY.PDF.

[43] Laufer, Alisa, Howard Shatz, and Omar Danaf. 2025. *Implications of Russia's War on Ukraine for the US and Allied Defense Industrial Bases*. RAND. RRA3141-3. https://www.rand.org/pubs/research_reports/RRA3141-3.html.

[44] O'Rourke, Ronald. 2024. *Multiyear Procurement (MYP) and Block Buy Contracting in Defense Acquisition: Background and Issues for Congress*. Congressional Research Service. R41909. https://sgp.fas.org/crs/natsec/R41909.pdf.

[45] Carberry, Sean. 2023. "Just In: Ukraine War Is Exposing NATO Interoperability Gaps." *National Defense*. July 18. https://www.nationaldefensemagazine.org/articles/2023/7/18/ukraine-war-is-exposing-nato-interoperability-gaps.

[46] US Department of State Bureau of Political-Military Affairs. 2025. "Fiscal Year 2024 U.S. Arms Transfers and Defense Trade." https://www.state.gov/fiscal-year-2024-u-s-arms-transfers-and-defense-trade/.

[47] Council on Supply Chain Resilience. 2024. *2021-2024 Quadrennial Supply Chain Review*. https://bidenwhitehouse.archives.gov/wp-content/uploads/2024/12/20212024-Quadrennial-Supply-Chain-Review.pdf.

[48] Office of the Under Secretary of Defense for Acquisition and Sustainment. 2020. *Fiscal Year 2020 Industrial Capabilities Report to Congress*. https://apps.dtic.mil/sti/citations/AD1121517.

[49] US Geological Survey. 2024. *Mineral Commodity Summaries 2024*. US Department of the Interior. https://www.usgs.gov/publications/mineral-commodity-summaries-2024.

[50] US Government Accountability Office. 2024. *National Defense Stockpile: Actions Needed to Improve DOD's Efforts to Prepare for Emergencies*. https://www.gao.gov/products/gao-24-106959.

[51] Dress, Brad. 2024. "Navy Pushes to Catch up to China's Superiority at Sea." The Hill. Sept. 30. https://thehill.com/policy/defense/4904379-us-navy-strategy-south-china-sea/.

[52] Office of the Under Secretary of Defense for Acquisition and Sustainment. 2019. *Fiscal Year 2019 Industrial Capabilities Report to Congress*. https://apps.dtic.mil/sti/citations/AD1109449.

[53] US Government Accountability Office. 2019. *Military Depots: Actions Needed to Improve Poor Conditions of Facilities and Equipment That Affect Maintenance Timeliness and Efficiency*. https://www.gao.gov/products/gao-19-242.

[54] Department of Defense. 2022. *Securing Defense-Critical Supply Chains*. https://apps.dtic.mil/sti/citations/AD1163223.

[55] Naval Facilities Engineering Systems Command. "Shipyard Infrastructure Optimization Program." Accessed June 25, 2025. https://www.navfac.navy.mil/PEO-Industrial-Infrastructure/PMO-555-SIOP/.

[56] Frost & Sullivan. 2024. *US Military Naval Vessel Maintenance, Repair, and Overhaul Industry Growth Opportunities*.

[57] US Government Accountability Office. 2024. *Columbia-Class Submarine: Overcoming Persistent Challenges Requires Yet Undemonstrated Performance and Better-Informed Supplier Investments*. https://www.gao.gov/products/gao-24-107732.

[58] OpenSecrets. "Sector Profile: Defense." https://www.opensecrets.org/federal-lobbying/sectors/summary?cycle=2024&id=D&utm_source=chatgpt.com.

This report was written by CNA's Systems, Tactics, and Force Development Division (STF).

STF focuses on systems and platforms at the tactical level of warfare, providing classical warfare analyses to help the US Navy and Department of Defense win the great power competition while meeting other warfighting requirements to simultaneously deter and defeat lesser threats. The division's mission includes analyzing and assessing alternative combinations of networks, sensors, weapons, and platforms to provide maritime warfighting capabilities in all warfare areas under realistic employment conditions for current operations and future force architectures.

Dedicated to the Safety and Security of the Nation

www.cna.org

About CNA

CNA is a not-for-profit analytical organization dedicated to the safety and security of the nation. With nearly 700 scientists, analysts, and professional staff across the world, CNA's mission is to provide data-driven, innovative solutions to our nation's toughest problems. It operates the Center for Naval Analyses—the Department of the Navy's federally funded research and development center (FFRDC)—as well as the Institute for Public Research. The Center for Naval Analyses provides objective analytics to inform the decision-making by military leaders and ultimately improve the lethality and effectiveness of the joint force. The Institute for Public Research leverages data analytics and innovative methods to support federal, state, and local government officials as they work to advance national and homeland security.

DRM-2025-U-042373-Final