From the Editor: An Introduction to "Decisions Facing US Navy for the Future of the Columbia Class Submarine"

The Challenge of Building the Navy's Next SSBN

Ohio-class ballistic missile submarine USS *Maine* (SSBN 741) returns to Naval Base Kitsap-Bangor

U.S. NAVY PHOTO BY MASS COMMUNICATION SPECIALIST 1ST CLASS RYAN RILEY

SOME OF THE MOST critical challenges in naval engineering are not technical—they are decisions. The Columbia-class submarine program sits at the center of one of the Navy's most consequential trade spaces: delivering the next generation of strategic deterrence on time, within budget, and with no margin for failure.

This paper presents the program as a case study in acquisition and decision-making under pressure. With the Ohio-class fleet nearing the end of its service life, the Columbia-class must be delivered on schedule to avoid a gap in the nation's sea-based nuclear deterrent. At the same time, the program faces familiar but unforgiving constraints: cost growth, schedule pressure, software integration challenges, and industrial base limitations.

Rather than offering a single solution, the authors frame the problem as a set of competing priorities—cost, schedule, performance, and risk—and challenge readers to think critically about how those trade-offs should be managed. The case highlights the reality that even the most advanced engineering programs succeed or fail based on how well these competing demands are balanced.

For the naval engineering community, the takeaway is clear: delivering capability at scale requires more than technical excellence. It requires disciplined decision-making, clear prioritization, and an understanding that affordability and industrial capacity are as much a part of the system as the submarine itself.

Decisions Facing US Navy for the Future of the Columbia Class Submarine

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Abstract

This case analysis is written to produce an active learning environment to increase the capability of acquisition/program management professionals and senior leaders regarding program planning, decision-making, and affordability. Ballistic missile submarines (SSBNs) are a stealthy, survivable launch platform that contributes to strategic deterrence. Ohio-class SSBNs, which have filled the role of sea-based deterrence for the last 40 years, are nearing the end of their planned service life. To prevent a gap in nuclear deterrent capability, the successor to the Ohio-class, the Columbia-class, must be built to meet the Navy initial operating date requirements. However, the Columbia-class submarine is experiencing setbacks due to multiple issues with requirements, software development, funding, industrial base capacity and capability, and quality assurance with shipyards and manufacturers. This case analysis presents the Columbia-class submarine acquisition program and the future challenges facing the Navy. This research encourages critical analysis to increase the capability of acquisition sciences professionals regarding balancing of cost, schedule, and performance requirements within technical risk, shipbuilding capacity/capability and affordability constraints. Affordability is always a major factor in development and procurement decisions for programs involving the development and integration of cutting-edge technologies and constrained by budgeted dollars. The case learning objectives include critical thinking, resource management, and problem-solving through stakeholder analysis, option analysis, and recommendations for the path forward.

Introduction

The Chief of Naval Operations (CNO) faced a difficult problem in the first quarter of 2022. The CNO is responsible to the Secretary of the Navy (SECNAV) for the "command, utilization of resources, and operating efficiency of the operating forces of the Navy" (United States Navy, n.d.). In conducting his charge, the CNO faces difficult challenges for the Navy. One challenge is ensuring the timely delivery of the Columbia-class submarine. The CNO just received a program update from Program Executive Officer (PEO) Strategic Submarines who was responsible for the Columbia-class submarine program. The PEO highlighted the release of the Congressional Research Service (CRS) report on the Columbia-class submarine and provided his viewpoint on the most pressing obstacles to delivering the future USS Columbia on time. The CNO knew the success of the program was a matter of national security. Failing to deliver the Columbia-class submarine on time would result in a nuclear strategic deterrence gap for the United States. However, with little schedule margin remaining and additional pressures to minimize program cost growth, the path forward was unclear. Were adjustments necessary for the cost, schedule, and performance requirements of the approved acquisition program baseline (APB)?

KEYWORDS: ship building, affordability, decision-making, critical thinking, project management

Background

Deep under the ocean's waves and across the globe, U.S. Navy nuclear ballistic missile submarines (SSBN) are on silent patrol performing the nation's "highest priority mission"—strategic deterrence (Lopez, 2021). This mission is conducted by Ohio-class submarines. Each Ohio-class SSBN, depicted in Figure 1, carries up to 24 Trident II submarine-launched ballistic missiles (SLBMs) and serves to dissuade U.S. adversaries from conducting a nuclear attack for fear of retaliation (Submarine Industrial Base Council, 2017). After decades of service, the Ohio-class SSBNs are beginning to reach the end of their already extended 42-year service life (Eckstein, 2020b, para. 1). To continue the legacy of strategic deterrence, the Department of Defense (DOD) is developing a replacement for the Ohio-class Submarine: the Colombia-class submarines (depicted in

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FIGURE 1. USS Wyoming (SSBN 742).
SOURCE: REBARICH (2008).

FIGURE 2. Artist's rendering of the future Columbia-class ballistic missile submarine.
SOURCE: U.S. DEPARTMENT OF DEFENSE (N.D.).

Figure 2).

The first SSBN in the Columbia class, the USS Columbia, is under construction to be completed by 2030 and ready to execute its first strategic deterrence patrol in 2031 (Government Accountability Office [GAO], 2021, p. 1). According to the CNO, "[the] Columbia-class is our number one acquisition priority" and "these submarines need to be delivered on time, on budget, and ready for the fight—we have no margin to fall behind" (U.S. Navy Office of Information, 2022). However, program delays for the USS Columbia threaten its scheduled delivery. If USS Columbia is not delivered on time and conducting its first patrol by 2031, the United States faces the unpalatable outcome of having an insufficient amount of SSBNs to fully perform the strategic deterrence mission at sea.

Strategic Deterrence

SSBNs play an integral role in strategic deterrence. Fourteen SSBNs currently patrol the world's oceans, provide an undetectable launch platform, and discourage the use of nuclear weapons by U.S. adversaries. As of 2022, nine countries had access to nuclear weapons (Federation of American Scientists, n.d., para. 1). In addition to the U.S., the United Kingdom, France, Israel, Pakistan, India, China, Russia, and North Korea contain nuclear weapon stockpiles that amount to approximately 9,400 warheads at the ready for military use (Federation of American Scientists, n.d., para. 5). The detonation of a nuclear warhead has a destructive power that includes fatal levels of radiation, catastrophic pressure waves, superheated fireballs, accompanying thermal flashes, and substantial amounts of long-lasting nuclear fallout that can remain for years following the explosion (Wolfson & Dalnoki-Veress, 2022). Despite the considerable number of nuclear weapons available for use, no strategic nuclear weapons have been used against another country since the bombing of Hiroshima and Nagasaki at the end of World War II (United Nations Office for Disarmament Affairs, 2021, para. 1). One reason for this enduring nuclear peace is strategic deterrence.

The aim of strategic deterrence, the "highest priority mission of the Department of Defense," is to dissuade another country from launching nuclear weapons at the U.S. out of fear of a retaliatory strike (Lopez, 2021). The U.S. uses a "nuclear triad" to provide a credible and capable source of strategic deterrence. The nuclear triad is composed of three components: air, land, and sea-based deterrence. Air-based deterrence is accomplished by the U.S. Air Force by outfitting airframes with nuclear weapons. More specifically, the Air Force B-52 Stratofortress bombers and B-2 Spirit bombers carry gravity-based nuclear bombs, and the F-15E Strike Eagle fighters carry nuclear cruise missiles (OSD Nuclear and Missile Defense Policy, 2020, p. 7). The Air Force is also responsible for land-based strategic deterrence. Minuteman III intercontinental ballistic missiles (ICBMs) are "spread out over 400 hardened, underground silos" (OSD Nuclear and Missile Defense Policy, 2020, p. 3), ready to strike. Sea-based deterrence is the responsibility of the SSBNs of the U.S. Navy.

Each portion of the nuclear triad offers its own unique advantages, but collectively they establish a formidable source of strategic deterrence. The land-based strategic deterrence afforded by U.S. ICBMs represents the most "responsive" leg of the nuclear triad. The president can, at any time, give the order to launch ICBMs through methods of "assured connectivity" (OSD Nuclear and Missile Defense Policy, 2020, p. 3). ICBMs are staffed by Air Force personnel and can respond

immediately to a launch order (OSD Nuclear and Missile Defense Policy, 2020, p. 3). Meanwhile, air-based deterrence provides the most "flexible" (OSD Nuclear and Missile Defense Policy, 2020, p. 7) leg of the nuclear triad. Air Force nuclear weapon–capable airframes are a mobile, visual strategic deterrent that patrol forward-deployed air space, serving as a reminder of the "U.S. commitments to its security and the security of its allies and partners" (OSD Nuclear and Missile Defense Policy, 2020, p. 7). If required to launch a nuclear payload, air-launched cruise missiles (ALCMs) offer a large degree of flexibility through their advanced targeting capabilities. According to the article, "Importance of Modernizing the Nuclear Triad," B-52s can "carry up to 20 ALCMs, allowing one bomber to threaten 20 geographically separated targets" simultaneously (OSD Nuclear and Missile Defense Policy, 2020, p. 7). The U.S. Navy's SSBN fleet, which conducts the sea-based strategic deterrence mission, is the only platform that represents a clandestine, survivable threat to U.S. adversaries. According to the Center for Arms Control and Non-Proliferation, the "sea-leg of the triad is often considered most essential, since submarines are difficult to track and destroy" (Schumann, 2021, para. 8). Given this noteworthy distinction, SSBNs have and will continue to receive a significant amount of attention and funding. To appreciate the state-of-the-art capabilities that will allow the Columbia-class submarine to execute the sea-based leg of the nuclear triad, it is important to understand the state-of-the-practice class Ohio-class SSBNs.

Ohio-Class Ballistic Missile Submarine

The first ship of the Ohio class, USS Ohio (SSBN 726), was commissioned on November 11, 1981 (General Dynamics Electric Boat, n.d.). The Ohio-class submarine was the successor to the "41 for Freedom" fleet ballistic missile (FBM) submarines, which were comprised of five different classes: the George Washington, Ethan Allen, Lafayette, James Madison, and Benjamin Franklin (Naval History and Heritage Command, 2021). Each of the earlier variants of FBM submarines could carry 16 Polaris missiles, and in later variants, Poseidon C-3 or Trident I C-4 missiles (Strategic Systems Platforms, n.d.). The FBM submarines provided successful strategic deterrence patrols for years. However, advances in submarine technology and the desire to equip vessels with substantial numbers of Trident ICBMs led to the development of the Ohio-class submarines.

Eighteen Ohio-class SSBNs were commissioned between 1981 and 1997 (General Dynamics Electric Boat, n.d.). The first four Ohio-class SSBNs, which completed strategic deterrence patrols, were converted into guided nuclear missile submarines (SSGNs) from 2000 to 2010. SSGNs are SSBNs that are outfitted with Tomahawk land attack missiles (TLAMS) instead of ICBMs. The remaining 14 SSBNs provide the sea-based leg of strategic deterrence today.

FIGURE 3. Ohio-Class Submarine, USS Henry M. Jackson (SSBN 730).

SOURCE: U.S. NAVY (2015).

Ohio-class submarines, an example of which is depicted in Figure 3, are 560-foot-long nuclear-powered warships that can carry up to 24 Trident I C-4 or Trident II D-5 missiles. They are homeported in either Kings Bay, GA, or Bangor, WA.

Each SSBN has two crews (known as the blue and gold crews), which operate the submarine on its nominal deployment cycles. One crew takes the submarine to sea for a strategic deterrence patrol that lasts 75 to 90 days. Once the strategic deterrence patrol is complete, the submarine returns to port, and a crew turnover occurs. Once the new crew has taken responsibility for the submarine, a 30-day maintenance period begins. When the maintenance period is complete, the submarine goes back to sea. The crew that has returned from sea and is in port operates submarine simulators, conducts training, and plans for the upcoming maintenance period following crew turnover.

Columbia-Class Ballistic Missile Submarine

The decision to replace the Ohio-class submarine with another "sea-based strategic deterrent" originated out of an agreement between President George W. Bush and U.K. Prime Minister Tony Blair in 2006 to have their "next generation SSBNs carry the Trident II D-5 Submarine Launches Ballistic Missiles (SLBMs)" (O'Rourke, 2022, p. 37). After the Joint Requirements Oversight Committee approved an initial capabilities document (ICD), the Ohio Replacement Program (ORP) office was established in 2008 (O'Rourke, 2022, p. 37). Milestone A for the ORP was approved on January 10, 2011 (O'Rourke,

2022, p. 38). Following the approval of Milestone A, in 2016 the ORP was renamed the "Columbia Class Program" (O'Rourke, 2022, p. 4). Milestone B was approved on January 4, 2017 (O'Rourke, 2022, p. 38), and the Navy officially started construction of the first Columbia-class submarine in November 2020 (Eckstein, 2020a, para. 1). A list of the major developments for the Columbia-class submarine can be seen in Table 1.

The Columbia-class submarine will be the world's state-of-the-art SSBN. Some of these innovative technologies can be seen in Figures 4 and 5. The Columbia class will feature a nuclear reactor that, unlike that of the Ohio class, requires no refueling for the lifetime of the submarine (Larson, 2021).

The new submarine class also features an electric-drive propulsion system and an X-shaped stern configuration, which will increase the ability of the submarine to remain undetected (Osborn, 2018). The Columbia-class submarine will carry up to 16 Trident D-5 missiles. This is eight fewer missiles than the Ohio-class submarine, which carries up to 24 Trident D-5 missiles. However, Columbia-class submarines will maintain the same number of overall missiles at sea because the Columbia-class submarines will not need to conduct mid-life refueling of the nuclear reactor. Fewer lengthy refueling periods result in fewer Columbia-class submarines in port and an increased number of SSBNs at sea (O'Rourke, 2022, p. 5).

12 Columbia-class SSBNs are set to replace the fourteen active Ohio- class SSBNs over the next 20 years, with the lead submarine to be delivered to the Navy no later than 2030 with the first strategic deterrence patrol no later than 2031. The Columbia-class SSBNs offer a large upgrade in capability over the Ohio-class SSBNs. In addition to the

FIGURE 4. Columbia-class submarine size and deterrent capability.
SOURCE:GENERAL DYNAMICS (N.D.).

Date	Significant Development Description
July 2008	USD AT&L issues ADM directing entry into the Concept Refinement Phase and conduct of an Analysis of Alternatives.
October 2008	Secretary of Defense sends letter to United Kingdom (UK) Secretary of State for Defense to affirm the U.S.-UK Mutual Defense Agreement and cost sharing for the Common Missile Compartment.
September 2010	SCP approved with new design SSBN based on 12 ships with 16 - 87" missile tubes.
January 2011	Milestone A ADM issued which authorized entry into Technology Maturation and Risk Reduction (TMRR) phase to complete a new design SSBN based on 12 ships with 16 - 87" missile tubes.
February 2012	PB 2013 shifts lead ship construction from FY 2019 to FY 2021; the two year recapitalization delay removed all margin during the OHIO-OHIO Replacement (OR) transition period (FY 2027–FY 2042); any delay in OR delivery or unexpected aging impact to OHIO will have significant impacts on SSBN Ao.
December 2012	RDT&E Design Contract issued to General Dynamics – Electric Boat.
December 2014	National Sea-Based Deterrence Fund established by Public Law 113-291.
November 2015	Incremental funding authority and authority to enter in contracts for Advance Construction and economic order quantity provided by Public Law 114-92.
January 2017	Milestone B APB approved (Program Initiation).
September 2017	Award of the Integrated Product and Process Development (IPPD) contract. The Navy has transitioned all design efforts from the OHIO Replacement Research & Development (R&D) Design contract to the IPPD contract.
September 2018	Award of the Two Year Advance Procurement Funding modification to the IPPD contract.
February 2019	APB updated to reflect actual award of IPPD contract (September 2017) and align affordability targets with approved CDD.

TABLE 1. History of significant developments for the Columbia-class submarine.
SOURCE: U.S. DEPARTMENT OF DEFENSE (2019).

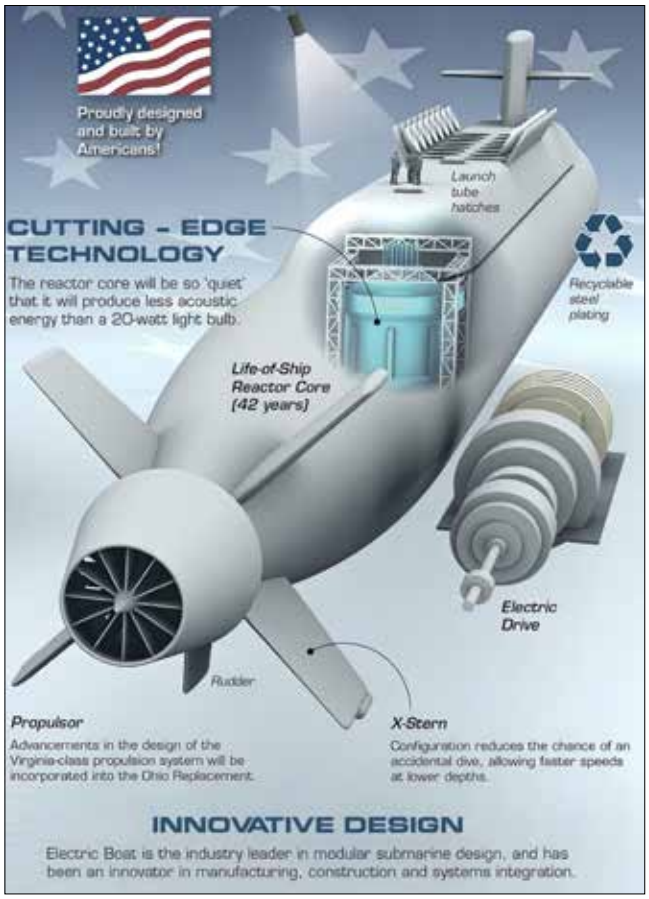

FIGURE 5. Cutting-edge technology on the Columbia-class submarine.

SOURCE: GENERAL DYNAMICS (N.D.).

nuclear reactor, electric-drive propulsion system, an X-shaped rudder/stern plane system, the Columbia will integrate the most modern sonar suite and the most advanced sound silencing capabilities. Additionally, the Columbia-class submarine carries the Trident II D-5 Submarine Launched Ballistic Missiles (SLBMs) as seen in Figure 6. These are the same nuclear weapons that are carried by the Ohio-class SSBNs. Utilizing this capable weapon reduces the risk of a delay in the first Columbia-class strategic deterrence patrol in 2031 by avoiding the development and acquisition of a new nuclear weapon.

Nuclear strategic deterrence is one of the most important missions of the DOD, making the Columbia-class submarine acquisition program critical for national security. As the Ohio-class submarines begin to reach the end of their useful service life, Columbia-class submarines must be ready to replace them. In the worst case, if the first Columbia-class submarine is not ready to conduct its first strategic deterrence patrol by 2031, there is a potential for a nuclear strategic deterrence gap, which could potentially jeopardize the national security.

FIGURE 6. Unarmed Trident II D-5 missile launched from a ballistic missile submarine.

SOURCE: U.S. NAVY (N.D.).

Big "A" Acquisition

The CNO knew the difficulties PEO Strategic Submarines was facing. The PEO was responsible for managing the "triple constraint" of the program's acquisition program baseline: cost, schedule, and performance. Though a simple concept, balancing the triple constraints involves complex decisions. A PEO or program manager (PM) can optimize the triple constraint for two of its three variables with concessions for the other. As an example, the PEO could focus on delivering a quality submarine on time (focusing on performance and schedule) at the expense of increased the overall lifecycle program costs. Conversely, the PEO could choose to drastically maintain the schedule and cut costs for the program at the risk of decreasing quality or performance. None of these decisions concerning the triple constraint, however, can be made in isolation. A PEO or PM finds themselves eternally in the middle of the Big "A" acquisition system. Big "A" acquisition consists of three interacting systems: the Joint Capability Integration and Development System (JCIDS), the Programming, Planning, Budgeting and Execution System (PPBE), and the Defense Acquisition Management System, commonly referred to as little "a" acquisition or more recently, the Adaptive Acquisition Framework (Moran, 2008). Figure 7 provides a visual representation and summary of the Big "A" concepts.

The JCIDS process is responsible for requirements generation and is a needs-driven process. The need assessed by the JCIDS process is defined in the initial capabilities document (ICD), and discrete operational requirements are derived from the ICD in the capability development document (CDD). In the case of the Columbia-class program, that need is providing a source of sea-based strategic deterrence. The PPBE process is responsible for the allocation of resources to programs. Unlike the other two parts of Big "A" acquisition, the PPBE process is

FIGURE 7. Big "A" acquisition.

SOURCE: MORTLOCK (2021).

a calendar-driven system. The final portion of Big "A" acquisition is the AAF, which is an events-driven system. The PEO or PM guides their programs along one of the pathways of the Adaptive Acquisition Framework (AAF) as seen in Figure 8. The Columbia-class submarine program follows the major capability acquisition pathway that entered the engineering and manufacturing development (EMD) phase following an approved milestone B decision in 2017. PEO Strategic Submarines' major challenge was to manage the APB (cost, schedule, and performance constraints) within the Big "A" environment.

Columbia-Class Acquisition Program Baseline

The current acquisition program baseline (APB) for the Columbia-class submarine was approved on February 25, 2019. An APB is developed by the Navy, is approved by the milestone decision authority (MDA), and details the threshold and objective values for cost, schedule, and performance requirements. These cost, schedule, and performance sections from the Columbia program APB are presented in Tables 2, 3, and 4, respectively.

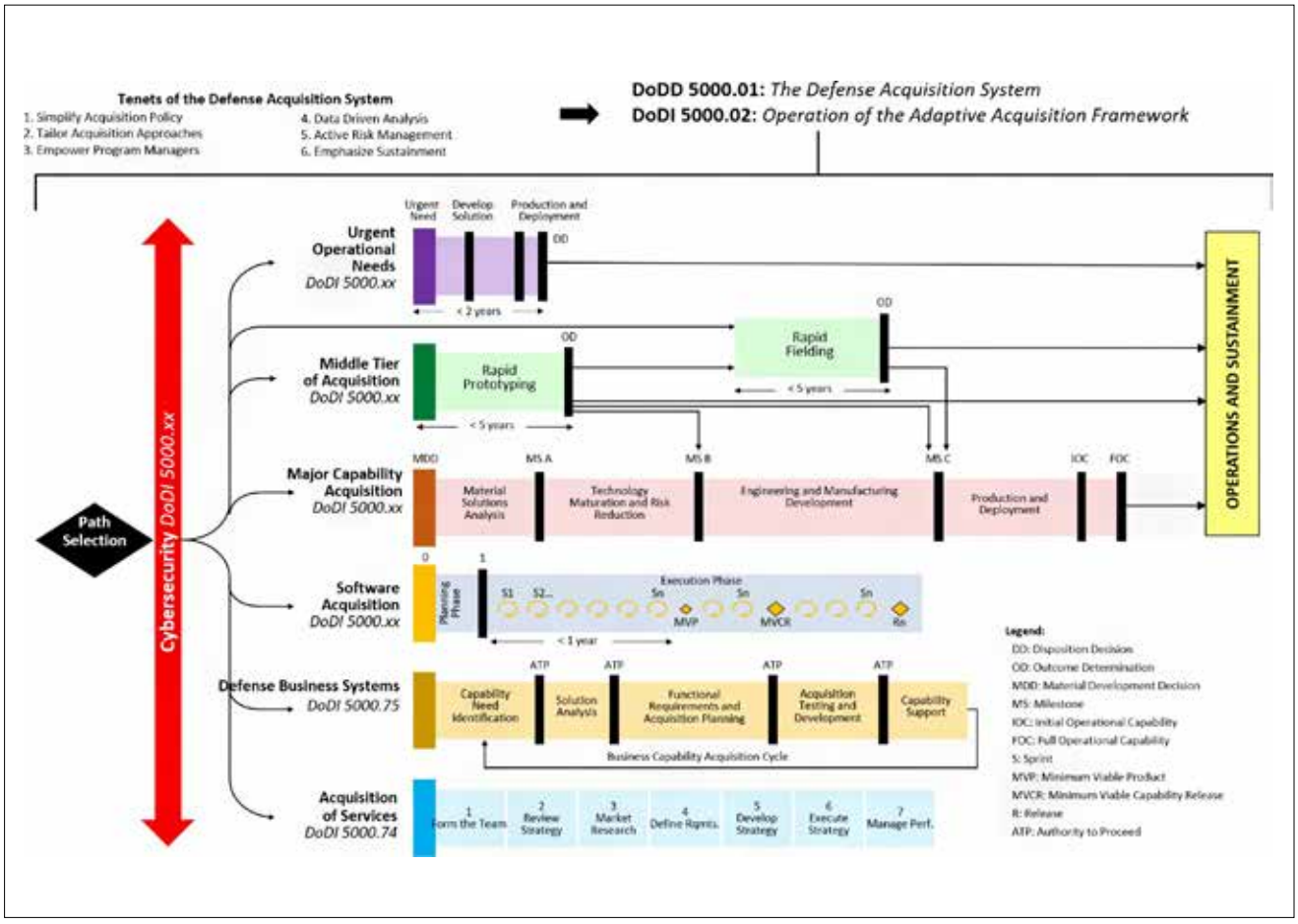

FIGURE 8. Adaptive acquisition framework.

SOURCE: DEFENSE ACQUISITION UNIVERSITY (N.D.).

Challenges Facing The Program

Despite the progress made on the Columbia-class submarine, delays in early construction were threatening timely delivery to the fleet (Government Accountability Office [GAO], 2021, p. 1). These specific problems include a "supplier base that is roughly 70% smaller than in previous shipbuilding booms," an "inexperienced shipyard workforce," "continuing challenges with … computer-aided software that … is [being used] to design the submarine," and "quality problems with supplier materials" (GAO, 2021, pp. 1, 20). If the Columbia-class submarine is not ready to make its "first patrol in fiscal year 2031 … [the United States will experience] a deterrence gap … [that would have] far-reaching consequences for the nation's defense" (GAO, 2021, p. 1). Given the magnitude of the consequences of a delay in the construction of the Columbia-class submarine and the $128 billion that the Navy plans to invest to create the 12 ships in the class, the Government Accountability Office (GAO) was tasked with "assessing the Navy's efforts to complete the design for the lead Columbia-class submarine and actions that the shipbuilders and the Navy have taken to prepare for construction and ensure the lead submarine is delivered according to schedule and quality expectations" (GAO, 2021, p. 2).

Total Acquisition Cost

Appropriation	BY 2017 $M			BY 2017 $M	TY $M		
	SAR Baseline Development Estimate	Current APB Development Objective	Threshold	Current Estimate	SAR Baseline Development Estimate	Current APB Development Objective	Current Estimate
RDT&E	12648.1	12648.1	13912.9	12646.7	13020.3	13020.3	13039.4
Procurement	87426.5	87426.5	96169.2	86117.0	115044.3	115044.3	113563.8
Flyaway	--	--	--	84275.3	--	--	111110.9
Recurring	--	--	--	79217.1	--	--	105415.6
Non Recurring	--	--	--	5058.2	--	--	5695.3
Support	--	--	--	1841.7	--	--	2452.9
Other Support	--	--	--	1841.7	--	--	2452.9
Initial Spares	--	--	--	0.0	--	--	0.0
MILCON	147.3	147.3	162.0	156.0	173.4	173.4	186.2
Acq O&M	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100221.9	100221.9	N/A	98919.7	128238.0	128238.0	126789.4

Current APB Cost Estimate Reference

SCP dated September 26, 2016

Cost Notes

No cost estimate for the program has been completed in the last year.

Total Quantity

Quantity	SAR Baseline Development Estimate	Current APB Development	Current Estimate
RDT&E	0	0	0
Procurement	12	12	12
Total	12	12	12

TABLE 2. Cost summary.

SOURCE: U.S. DEPARTMENT OF DEFENSE (2019).

Events	SAR Baseline Development Estimate	Current APB Development Objective	Threshold	Current Estimate
Milestone A	Dec 2010	Dec 2010	Dec 2010	Dec 2010
Pre-RFP Release DAB	Dec 2015	Dec 2015	Dec 2015	Dec 2015
Preliminary Design Review	Apr 2016	Apr 2016	Apr 2016	Apr 2016
Milestone B	Nov 2016	Jan 2017	Jan 2017	Nov 2016
Integrated Process and Product Development Contract Award	Jan 2017	Sep 2017	Sep 2017	Sep 2017
Two Year Advance Procurement Funding Modification	Oct 2018	Sep 2018	Sep 2018	Sep 2018
Critical Design Review	Apr 2020	Apr 2020	Oct 2020	Apr 2020
Lead Ship Authorization / Construction Start	Oct 2020	Oct 2020	Apr 2021	Oct 2020
Block I Contract Award	Oct 2020	Oct 2020	Apr 2021	Oct 2020
Lead Ship Contract Delivery	Apr 2027	Apr 2027	Oct 2027	Oct 2027
Initial Operational Test and Evaluation Complete	Feb 2029	Feb 2029	Aug 2029	Aug 2029
Lead Ship First Deployment Start	Apr 2030	Apr 2030	Oct 2030	Oct 2030
Initial Operational Capability	Apr 2030	Apr 2030	Oct 2030	Oct 2030

TABLE 3. Schedule of events.

SOURCE: U.S. DEPARTMENT OF DEFENSE (2019).

Software Issues

Electric Boat, the Columbia-class SSBN program contractor, switched to a new computer-aided software tool for the Columbia-class SSBN because the software for the previous tool was "no longer supported by the original developer" (GAO, 2021, p. 6). The purpose of the computer-aided software tool is to design arrangements, disclosures, and material orders, which are required to develop the submarine (GAO, 2021, p. 7). The arrangements, which are completed first, are 3D models of the steel structure, the electrical systems, and the piping systems (GAO, 2021, p. 7). Once the arrangements have been completed, the next step is to design the disclosures. The disclosures "complete the design work for even the lowest-level items of the submarine, including material information" (GAO, 2021, p. 7). A completed disclosure lends way to the development of work instructions, which provide shipyard workers with the procedures and parts required to build any given part of the ship, and the material orders, which allow the generation of contracts to order all required parts (GAO, 2021, p. 7).

One major advantage of the new computer-aided design tool was that it

was supposed to "reduce the average hours needed to complete design disclosures by almost half of the time required for the Virginia class program" (GAO, 2021, p. 13). This would enhance the ability of the Columbia-class to stay on schedule because completed disclosures allow the program office to accurately order parts and prepare workers for submarine assembly. Unfortunately, issues with the new software have resulted in delays in disclosure and work instruction completion. The GAO cites software trouble as the major cause of delay in the construction of the Columbia-class submarine (GAO, 2021, p. 13). In the absence of work instructions, the shipyard cannot begin building portions of the submarine because they do not have procedures for their workers to follow (GAO, 2021, p. 16). Additionally, delays in disclosure completion have resulted in delayed orders of construction materials and subsequent construction because "Electric Boat cannot order materials until they are sufficiently defined in a disclosure" (GAO, 2021, p. 17). In 2021, the GAO estimated that "Electric Boat must increase its average work instruction completion rate by 29 percent in 2020 to support the planned construction pace." A Congressional Research Service (CRS) report states that "the shipbuilder [did not meet] the goal for design disclosures" (O'Rourke, 2022, p. 17).

SAR Baseline Development Estimate	Current APB Development Objective/Threshold		Demonstrated Performance	Current Estimate
Operations and Support (O&S) Cost KSA				
Average annual O&S cost per unit of $96M (CY 2010$)	Average annual O&S cost per unit of $119M (CY 2017$)	Average annual O&S cost per unit of $131M (CY 2017$)	TBD	$120.2M (CY2017$)
Net-Ready KPP				
Meet the requirements defined within the OR SSBN PIIT of the Common Submarine Information Support Plan	Meet the requirements defined within the OR SSBN PIIT of the Common Submarine Information Support Plan	(T=O) Meet the requirements defined within the OR SSBN PIIT of the Common Submarine Information Support Plan	TBD	Meet the requirements defined within the OR SSBN PIIT of the Common Submarine Information Support Plan
Training KPP				
OR SSBN crews are capable of being certified proficient for strategic patrol operations by the Group Commander upon completion of the normal PDTP in accordance with Fleet instructions	OR SSBN crews are capable of being certified proficient for strategic patrol operations by the Group Commander upon completion of the normal PDTP in accordance with Fleet instructions	(T=O) OR SSBN crews are capable of being certified proficient for strategic patrol operations by the Group Commander upon completion of the normal PDTP in accordance with Fleet instructions	TBD	OR SSBN crews are capable of being certified proficient for strategic patrol operations by the Group Commander upon completion of the normal PDTP in accordance with Fleet instructions
Space, Weight, Power, and Cooling (SWAP-C) KSA				
Future Growth Margin: 3% of Condition A-1 weight Cooling Capacity: 10% cooling capacity over the chill water design heat load Power – 10% electrical power future growth margin for ship's electrical loads at full power while underway at delivery	Future Growth Margin: 3% of Condition A-1 weight Cooling Capacity: 10% cooling capacity over the chill water design heat load Power – 10% electrical power future growth margin for ship's electrical loads at full power while underway at delivery	(T=O) Future Growth Margin: 3% of Condition A-1 weight Cooling Capacity: 10% cooling capacity over the chill water design heat load Power – 10% electrical power future growth margin for ship's electrical loads at full power while underway at delivery	TBD	Future Growth Margin: 3% of Condition A-1 weight Cooling Capacity: 10% cooling capacity over the chill water design heat load Power – 10% electrical power future growth margin for ship's electrical loads at full power while underway at delivery
Procurement Cost KCP				
Lead Ship End Cost Less Plans of $6.3B (2010$) using Navy Inflation / Deflation Indices Average Follow Ship Hulls 2-12 End Cost of $4.9B (2010$) using Navy Inflation / Deflation Indices	APUC of $7.3B (CY 2017$)	APUC of $8.0B (CY 2017$)	TBD	$7.18B (CY2017$)
Lead Ship First Deployment Key Schedule Parameter				
Third quarter of FY2030	Third quarter of FY 2030	First quarter of FY 2031	TBD	First quarter of FY 2031

TABLE 4. Performance characteristics.

SOURCE: U.S. DEPARTMENT OF DEFENSE (2019).

Submarine Supplier Base

The submarine supplier base is under significant strain to produce materials required for the timely production of the Columbia-class submarine. Electric Boat and Newport News, the only two private shipbuilders who construct nuclear-powered vessels for the U.S. Navy, "plan to deliver 39 nuclear submarines during the next 2 decades, which, if achieved, would represent a doubling in output over prior years" (GAO, 2021, p. 8). The thirty-nine submarines account for continuing to produce "two Virginia Class submarines per year through 2033 and one Columbia Class submarine per year starting in 2026" (GAO, 2021, p. 8). This pace of submarine construction has been unmatched since the height of the Cold War. Complicating the problem of increased demand for materials, the submarine supplier base has "shrunk by roughly 70–80 percent since the 1970s and 1980s" (GAO, 2021, p. 9). The GAO (2021) estimated that the number of suppliers has decreased from 17,000 to approximately 5,000 (p. 9). The PEO Strategic Submarines stated that "our most significant risk at the top of the list is our supplier industrial base" (O'Rourke, 2022, p. 12).

In addition to having a smaller and more fragile supplier base that is working at maximum capacity to deliver critical

materials for the Navy's most important acquisition program, the number of experienced workers has declined (GAO, 2021, p. 20). This has resulted in inexperienced workers delivering substandard quality materials to the Columbia-class lead shipbuilder, Electric Boat (GAO, 2021, p. 26). As a specific example, quality problems in the welds for the missile tubes that were discovered at the manufacturer "are likely to cause continued delays as formal construction begins" (GAO, 2021, p. 26).

Quality Assurance Issues

A strong quality assurance program not only is an industry best practice but also minimizes the probability of schedule delays and cost overruns. According to the GAO (2021), the "shipbuilder is responsible for delivering quality submarines that meet the Navy's specifications and … is tasked with ensuring and monitoring quality based on contract requirements" (p. 10). At this point, however, the GAO assessed that "supplier quality problems have persisted, but the Navy has not comprehensively reassessed when additional government inspections at suppliers are necessary" (GAO, 2021, p. 25), which is a major driver for schedule delays.

Risk of Schedule Delay

The Columbia-class program faced both technological risk and an aggressive production schedule as threats to schedule delay. The Columbia-class submarine contains technological upgrades over its predecessors. With each innovative technology introduced, there is a risk of schedule delay as the program office works through design and integration issues. According to the CRS, an example of a technological challenge that could threaten schedule is the electric-drive system, which is an upgrade from the steam-based propulsion system utilized on all other American nuclear submarines (O'Rourke, 2022, p. 12). The GAO warns that "based on leading acquisition practices, we consider technologies to be mature after successful testing of a prototype near or at the planned operational system configuration in a realistic environment" and that "additional development and testing are required to demonstrate the maturity of several technologies critical to performance" (O'Rourke, 2022, p. 15–16).

The lead ship of the Columbia-class is slated to be built in 84 months, approximately 7 months faster than the lead ship of any other submarine class (O'Rourke, 2022, 17). This record-breaking design and construction plan also comes at a time when General Dynamics and Huntington-Ingalls are building two Virginia-class submarines per year. According to the Virginia-class program office, in 2011 when production of Virginia-class submarines increased to two per year, they experienced "cost and schedule growth at shipyards" (O'Rourke, 2022, p. 17). It is also reasonable to conclude that adding a third submarine to the construction schedule will also result in additional schedule delays.

Risk of Cost Growth

Though the focus of the Columbia-class program office is delivering the new SSBNs on time, another concern is the risk of cost overrun (O'Rourke, 2022). The Columbia-class submarine is the Navy's "top priority program" and, therefore, is a program that "will be funded" (O'Rourke, 2022, p. 18). However, costs exceeding the amount budgeted for the submarine jeopardize other Navy construction efforts, which could affect the ability of the Navy to realize its strategic vision as currently planned.

The 2019 Congressional Budget Office (CBO) estimate showed that the cost of the first Columbia-class submarine would be "$14 billion, $700 million more than the Navy estimates" (O'Rourke, 2022, p. 20). Though there are reasons why the Navy may be underestimating its costs according to the CBO, the GAO assesses it is due to at least two factors. The first factor is not being able to take advantage of planned cost savings in the detailed design phase due to delays in disclosure completion (O'Rourke, 2022, p. 15). Second, the GAO assessed that the Columbia-class program office

Boat and budget	Estimated cost	Change from prior year	Cumulative change since FY2021
SSBN-826 (first boat)			
FY21 budget	14,393.4	—	—
FY22 budget	15,030.5	+637.1 (+4.4%)	+637.1 (+4.4%)
FY23 budget	15,179.1	+148.6 (+1.0%)	+785.7 (+5.5%)
SSBN-827 (second boat)			
FY21 budget	9,326.1	—	—
FY22 budget	n/a	n/a	n/a
FY23 budget	9,280.2	n/a	-45.9 (-0.5%)

Source: Table prepared by CRS based on Navy's FY2021-FY2023 budget submissions.
Note: n/a means not available.

TABLE 5. Change in estimated procurement costs since FY2021 budget (millions of then-year dollars, rounded to the nearest tenth).
SOURCE: O'ROURKE (2022).

had "overly optimistic assumptions about the labor hours needed to construct the submarines," which were not factored into cost estimates (O'Rourke, 2022, p. 21). The Columbia program office incorporated the loss of cost savings in the design process and updated the estimates of labor required to complete the first Columbia-class submarine. However, it is important to note that accurate cost estimates are a particularly difficult challenge for any lead ship in a new class due to unanticipated costs that are discovered during the acquisition process. From the FY21 budget, when the first Columbia-class submarine was first officially procured, to the most recent FY23 budget, estimated costs have been updated and are steadily increasing, as shown in Table 5.

These rising costs are concerning due to the impact they might have on the Navy's shipbuilding program at large. Another factor that could lead to increased program costs is the contract type for the first two Columbia-class submarines. The first two ships in the Columbia-class are being built under cost-plus incentive fee (CPIF) contracts (O'Rourke, 2022, p. 21). A CPIF contract is a "cost-reimbursement contract that provides for the initially negotiated fee to be adjusted later by a formula based on the relationship of total allowable costs to total target costs" (FAR 16.405-1, 2022). CPIF-type contracts transfer cost risks to the government from the contractor, and the government funds development costs within the scope of the contract above the original baseline estimates. In the case of the Columbia-class program, the likelihood of the government incurring costs more than the baseline is high because designing the lead ship in a class is a challenging endeavor, pushing the state of technology with unforeseen obstacles not initially anticipated.

Columbia-class submarines represent a substantial portion of the Navy's shipbuilding budget. Discounting the cost of the first Columbia-class submarine, which is the most expensive ship in a new class of ships, producing one Columbia-class submarine will cost about $8 billion per year of the Navy's shipbuilding budget until FY35 when all 12 Columbia-class submarines are scheduled to be completed (O'Rourke, 2022, p. 23). The significance of the cost of the Columbia-class submarine on the shipbuilding efforts of the Navy depends on the actual cost of producing a Columbia-class submarine and the money budgeted in any given year for shipbuilding. The larger the percentage of the Navy's shipbuilding budget the Columbia-class submarine has, the greater the possible impact on overall shipbuilding efforts.

Path Forward

The CNO and the PEO summarized a host of issues standing in between the Columbia-class submarine program and a successful strategic deterrence patrol in 2031. Each issue provided a stressor to at least one side of the triple constraint.

Schedule problems are one of the significant issues facing the Columbia-class submarine program. These schedule delays were caused in part by problems with the software used to design the submarine. The prime contractor's use of a new computer-aided software tool experienced issues, which resulted in delays. The next issue which has and may continue to cause schedule delays and affect performance is the significant strain on the submarine supplier base. The submarine supplier base represented a significant risk to the program. Not only is the construction of the Columbia-class submarine underway, but two Virginia-class submarines are being built per year to replace the aging fast-attack submarine fleet. This smaller supplier base is constantly competing for parts and skilled labor.

Another problem facing the schedule of the Columbia-class program office is the technological risk associated with the new SSBN. One specific risk was the maturity of the electric drive propulsion system. This system is a brand-new method of propulsion for American nuclear submarines, which had previously been powered by steam.

As if the schedule and technical pressures were not enough risk, cost risks existed. Pressure exists to improve the quality of cost estimates. Not accounting for the first submarine, which had an estimated cost of over $14 billion, each subsequent Columbia-class submarine was estimated at $8 billion apiece. The Columbia program represented a sizable portion of the Navy's overall shipbuilding budget, and in a worst-case scenario, would put pressure on other shipbuilding programs and potentially put the Navy's goal of 355 ships by the mid-2050s at risk.

The schedule for the Columbia class was certainly strained. All assumptions for the timely delivery of the Columbia-class submarine were based upon the threat of a strategic deterrence gap in 2031. This need was determined by the JCIDS process and captured in the Columbia-class APB. Would the validity of the need change if the existing Ohio-class SSBNs could extend their service lives any further? The service life of Ohio-class SSBNs was previously extended to accommodate delays in the Columbia-class submarine. Also, would there be any willingness from senior leaders to tolerate a temporary strategic deterrence gap until the Columbia-class submarine is completed? Both choices would lessen schedule pressure.

In addition to seeking to alleviate the schedule strain, the CNO also considered strengthening the submarine shipbuilding industrial base. A more robust industrial base would alleviate material supply issues. The larger industrial base can also increase the quality of its workforce, which would minimize rework, saving time, lowering costs, and increasing overall

performance. One way the industrial base could be strengthened is by employing a targeted use of Title III of the Defense Production Act (DPA). According to 50 U.S.C, Title III of the DPA "provides the president a unique and broad authority to ensure the timely availability of essential domestic industrial recourses to support national defense and homeland security requirements through the use of highly tailored economic incentives." Should a purchase commitment be utilized to "create a guaranteed demand to reduce the risk for industry to make their own investments?" (Lehman, n.d.). Should a direct loan be made to help accommodate for the "the risk tolerance being [beyond that of] the commercial market?" (Lehman, n.d.). Are there other incentives or provisions that should be considered?

A final risk to schedule came from the innovative technologies that were being introduced on the Columbia-class. There were different opinions regarding the technology and manufacturing readiness levels of critical technologies. Is conducting thorough development and operational testing to assess technical performance compliance, operational effectiveness, and operational suitability worth the time and cost investment? If a technical flaw is discovered early, it could save large schedule delays and costs in the future. And if minimizing technology risk was a primary consideration, would there be any interest in canceling the Columbia program and building new Ohio-class submarines? The Ohio-class are considered state-of-the-practice submarines. This would come from decreasing performance requirements, but a new line of Ohio-class submarines could certainly be created by 2031 and at lower cost than Columbia-class submarines.

Conclusion

The U.S. Navy's nuclear ballistic missile submarines (SSBN) are essential for strategic deterrence missions. The Navy operates 14 SSBNs that roam the world's oceans. These submarines are equipped with Trident II submarine-launched ballistic missiles (SLBMs). However, the Ohio-class SSBNs are beginning to reach the end of their already extended 42-year service life. USS Columbia is set to be completed and turned over to the Navy by 2030 and ready to execute its first strategic deterrence patrol in 2031. According to ADM Gilday, "[the] Columbia-class is our number one acquisition priority" and "these submarines need to be delivered on time, on budget, and ready for the fight – we have no margin to fall behind". USS Columbia class submarines will incorporate innovative technologies to include a nuclear reactor that requires no mid-life refueling, an electric-drive propulsion system, an X-shaped stern configuration, as well as a modern sonar suite and advanced sound silencing capabilities. The issue facing the Navy is risk to the 2031 IOC date. Challenges facing the program include a small supplier base, inexperienced shipyard workforce, immature computer-aided design software, quality problems with supplier materials, high technical risk, aggressive production schedule, program cost growth, and an outsized impact of the program on the overall Navy shipbuilding budget. Options the Navy could consider include investing more resources into the Columbia program, extending the service life of the Ohio-class submarines, accepting a strategic deterrence gap, cancelling the program, and investing in an Ohio-class upgrade program. Possible decision criteria to compare these options could include maximizing performance (deliver the most required capabilities), lowering costs (lower total life cycle costs), delivering on schedule (avoid deterrence gap), and lowering technical risk (incorporate "state of practice" rather "state of art" technologies). To determine the path forward for the Columbia program, senior Navy leadership must balance the criticality of avoiding a strategic deterrence gap and the need to preserve a robust shipbuilding industrial base, with program affordability, a desire for maximum performance requirements and accompanying the technical risk, cost and schedule to attain those capabilities. The future of the Columbia program, like other major defense acquisition programs, comes down optimally balancing not the triple constraint but the quadruple constraint of cost, schedule, performance and risk. NEJ

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