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ANALYSIS OF POSSIBLE SOLUTIONS TO SUPPORT THE TIMELY DELIVERY OF THE COLUMBIA CLASS SUBMARINE

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THESIS

ANALYSIS OF POSSIBLE SOLUTIONS TO SUPPORT THE TIMELY DELIVERY OF THE COLUMBIA CLASS SUBMARINE

by

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June 2022

Thesis Advisor: Robert F. Mortlock

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Ballistic missile submarines (SSBNs) are a stealthy, survivable launch platform that contributes to strategic deterrence, the number one mission of the Department of Defense. Ohio-class SSBNs, which have filled the role of sea-based deterrence for the last 40 years, are reaching their retirement criteria. In order to prevent a gap in nuclear deterrent capability, the successor to the Ohio-class, the Columbia-class, must be built according to schedule. However, the Columbia-class submarine is experiencing setbacks due to multiple issues with the software used to generate key design documents, an industrial base that is struggling to support the construction of three submarines per year (two Virginia-class fast attack submarines and one Columbia-class SSBN), and quality assurance issues with key manufacturers. With a mission as important as strategic deterrence on the line, developing a useful solution quickly is of the highest importance. This research analyzed the Columbia-class submarine acquisition program, generated a case study, and concluded with a case study analysis that utilizing the Defense Production Act Title III, which could re-bolster the submarine industrial base, and fully restoring and improving existing quality assurance programs, could increase the likelihood of delivering the first Columbia-class submarine on schedule while also optimizing for cost, performance, and technological risk.

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ABSTRACT

Ballistic missile submarines (SSBNs) are a stealthy, survivable launch platform that contributes to strategic deterrence, the number one mission of the Department of Defense. Ohio-class SSBNs, which have filled the role of sea-based deterrence for the last 40 years, are reaching their retirement criteria. In order to prevent a gap in nuclear deterrent capability, the successor to the Ohio-class, the Columbia-class, must be built according to schedule. However, the Columbia-class submarine is experiencing setbacks due to multiple issues with the software used to generate key design documents, an industrial base that is struggling to support the construction of three submarines per year (two Virginia-class fast attack submarines and one Columbia-class SSBN), and quality assurance issues with key manufacturers. With a mission as important as strategic deterrence on the line, developing a useful solution quickly is of the highest importance. This research analyzed the Columbia-class submarine acquisition program, generated a case study, and concluded with a case study analysis that utilizing the Defense Production Act Title III, which could re-bolster the submarine industrial base, and fully restoring and improving existing quality assurance programs, could increase the likelihood of delivering the first Columbia-class submarine on schedule while also optimizing for cost, performance, and technological risk.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAF	adaptive acquisition framework
APB	acquisition program baseline
ADM	admiral
ALCM	air-launched cruise missile
CAPT	captain
COA	course of action
CBO	Congressional Budget Office
CDD	capability development document
CNO	Chief of Naval Operations
CPIF	cost-plus incentive fee
CRS	Congressional Research Service
DAS	Defense Acquisition System
DPA	Defense Production Act
EMD	engineering and manufacturing development
DOD	Department of Defense
FBM	fleet ballistic missile
HBS	Harvard Business School
ICBM	intercontinental ballistic missile
ICD	initial capabilities document
JCIDS	Joint Capabilities Integration and Development System
KPP	key performance parameter
ORP	Ohio replacement program
PEO	program executive officer
PM	program manager
PPBE	Planning, Programming, Budgeting, and Execution System
RADM	rear admiral
TLAM	Tomahawk land attack missile
SECNAV	Secretary of the Navy
SLBM	submarine-launched ballistic missile
SSBN	ballistic missile nuclear submarine

SSGN	guided missile nuclear submarine
STRATCOM	U.S. Strategic Command
U.K.	United Kingdom

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I. INTRODUCTION

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 several Ohio-class submarines 24 hours a day, 365 days a year. Each Ohio-class SSBN, depicted in Figure 1, can carry up to 24 Trident II submarine-launched ballistic missiles (SLBMs) and serves to dissuade enemies of the United States from conducting a nuclear attack for fear of retaliation from an un-locatable source (Submarine Industrial Base Council, 2017). Despite honorably serving this country for many decades, the Ohio-class SSBNs are beginning to reach the end of their already extended 42-year service life (Eckstein, 2020b, para. 1). In order to continue the legacy of strategic deterrence, the Department of Defense is developing a replacement for the Ohio-class Submarine: the Colombia-class.

Figure 1. USS *Wyoming* (SSBN 742). Source: U.S. Navy photo by LT. Rebecca Rebarich (2008).

The Columbia-class SSBNs, the named successor to the Ohio-class SSBNs and depicted in Figure 2, are under construction. The first SSBN in the Columbia class, the 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 (Government Accountability Office [GAO], 2021, p. 1). According to the Chief of Naval Operations (CNO), Admiral Mike 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" (U.S. Navy Office of Information, 2022). However, program delays for the USS *Columbia* threaten its on-time 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.

Figure 2. Artist's rendering of the future Columbia-class ballistic missile submarine. Source: Navy illustration (n.d.).

A. PURPOSE OF RESEARCH

The purpose of this research is to review why the timely delivery of the Columbia-class submarine is vital to national security, examine the obstacles delaying the schedule for that timely delivery, present a case study that summarizes issues for the Columbia-class program office while challenging the reader to make decisions to appropriately optimize cost, schedule, performance, and technological risk and propose solutions in a follow-on analysis that will result in the prevention of a strategic deterrence gap.

B. METHODOLOGY

This thesis first presents relevant background information and a literature review to educate readers on the core principles of strategic deterrence, the role of SSBNs in the nuclear triad, the legacy and capabilities of the Ohio-class submarines, the newly anticipated capabilities of the Columbia-class submarine, the obstacles to the timely delivery of the Columbia-class submarine, the consequences to national security if the Columbia class is delivered late, and some relevant background information regarding possible solutions to support the timely delivery of the Columbia-class submarine. This information is then consolidated and presented in a case study that allows students to analyze the scenario and present their recommendations to optimize the correct mix of cost, schedule, and performance for the Columbia-class. Utilizing a case study allows students to work on their problem-solving and the ability to present a final, logical decision or recommendation. It also allows students to improve meta-skills such as preparation, discernment, bias recognition, judgment, collaboration, curiosity, and self-confidence (Nohria, 2021). The thesis concludes with an analysis of the case study as well as final conclusions.

C. ORGANIZATION

In Chapter II, I establish the need for the Columbia-class submarine by providing relevant background information on strategic deterrence, the role of SSBNs in the nuclear triad, and the legacy of the existing Ohio-class submarines. I also detail anticipated improvements on the next generation SSBN. Having established the need for a replacement for the Ohio-class submarines, I transition to Chapter III, the literature review. In this chapter, I provide the obstacles in the way of the delivery of the Columbia-class submarine which I researched from two major sources: a Government Accountability Office and a Congressional Research Service report. Chapter IV introduces the case study method, describes its benefits and lists the first principles of creating a case study. Utilizing the method I discussed in Chapter IV, I present my case study in Chapter V. This case study puts the reader in the position of the Chief of Naval Operations as he seeks to make the optimal decisions about how to prioritize cost, schedule, and performance as it relates to the Columbia-class program. I finish this thesis with Chapter VI, which offers my detailed analysis of the case study in the previous chapter and my final conclusions.

II. BACKGROUND

SSBNs have played an integral role in strategic deterrence since their inception. As of today, the United States has 14 SSBNs that roam the world's oceans and provide an undetectable launch platform, discouraging the worldwide use of nuclear weapons by adversaries of America.

A. STRATEGIC DETERRENCE

In 2022, nine countries have access to the most destructive tools the world has ever known: nuclear weapons (Federation of American Scientists, n.d., para. 1). In addition to the United States, the United Kingdom (U.K.), France, Israel, Pakistan, India, China, Russia, and North Korea contain nuclear weapon stockpiles that, in total, amount to approximately 9,400 warheads that are ready for military use (Federation of American Scientists, n.d., para. 5). The detonation of a single nuclear warhead has an incredible destructive power that can unleash a fatal level of radiation, a catastrophic pressure wave that can topple buildings with ease, a superheated fireball and accompanying thermal flash capable of creating a sweeping firestorm, and a large amount of damaging, long-lasting nuclear fallout that will remain in the days, weeks, and years following the explosion (Wolfson & Dalnoki-Veress, 2022). However, despite such a large number of nuclear weapons available for use, no strategic nuclear weapons have been used against another country in or outside of warfare since the bombing of Hiroshima and Nagasaki at the end of World War II (United Nations Office for Disarmament Affairs, 2021, para. 1). The most likely 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 United States out of fear of a retaliatory strike (Lopez, 2021). The United States 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 that normally carry conventional weapons with nuclear weapons. More specifically, the Air Force B-52H

Stratofortress bombers and B-2 Spirit bombers can be equipped with gravity-based nuclear bombs, and the F-15E Strike Eagle strike fighters can be equipped with 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 at any time. 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, and together 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 of the United States can, at any time, give the order to launch ICBMs through methods of "assured connectivity" (OSD Nuclear and Missile Defense Policy, 2020, p. 3) to ICBM silos. ICBMs are manned 24 hours a day, 7 days a week by qualified 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 can 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) can 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" (OSD Nuclear and Missile Defense Policy, 2020, p. 7) at the same time. However, 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 adversaries of the United States. 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 match. In order 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 better than ever before, it is important to understand the state-of-the-practice class of SSBNs: the Ohio class.

B. 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 completed numerous successful strategic deterrence patrols for years. However, advances in submarine technology and the desire to equip vessels with great 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 numerous 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 are carrying out the sea-based leg of strategic deterrence today.

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 will take the submarine to sea for a strategic deterrence patrol that lasts approximately 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.

Figure 3. Ohio-class submarine, USS *Henry M. Jackson* (SSBN 730). Source: U.S. Navy (2015).

C. COLUMBIA-CLASS BALLISTIC MISSILE SUBMARINE

The decision to replace the Ohio-class submarine with another "sea-based strategic deterrent" (SBSD) 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.

Table 1. History of significant developments for the Columbia-class submarine. Source: *SSBN 826 Columbia-class submarine* (2019).

History of Significant Developments Since Program Initiation

History of Significant Developments Since Program Initiation	
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- FY2042), 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.

The Columbia-class submarine will be the world's state-of-the-art SSBN. Some of these new technologies can be seen in Figures 4 and 5.

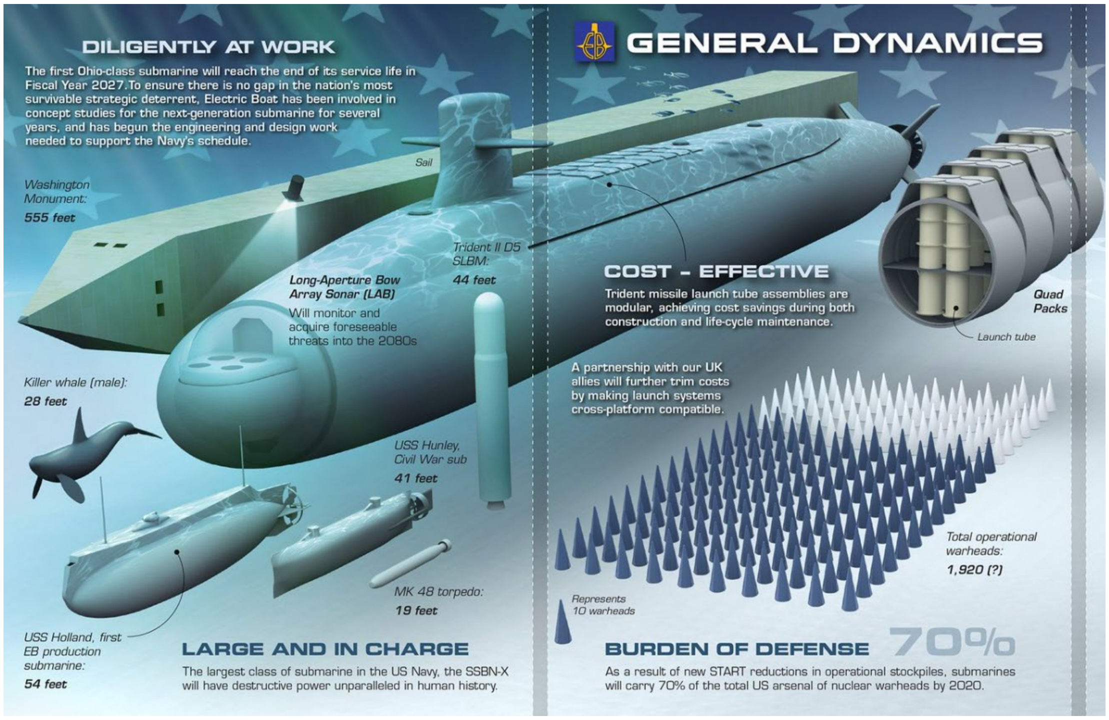

Figure 4. Columbia-class submarine size and deterrent capability. Source: General Dynamics (n.d.).

The Columbia class will feature a nuclear reactor that, unlike that of the Ohio class, will not require refueling for the lifetime of the submarine (Larson, 2021). The new submarine class will also feature the first electric-drive propulsion system and an X-shaped stern configuration, which will greatly increase the ability of the submarine to remain undetected (Osborn, 2018). The Columbia-class submarine will be capable of carrying up to 16 Trident D-5 missiles. This is eight fewer missiles than the Ohio-class submarine which can carry 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).

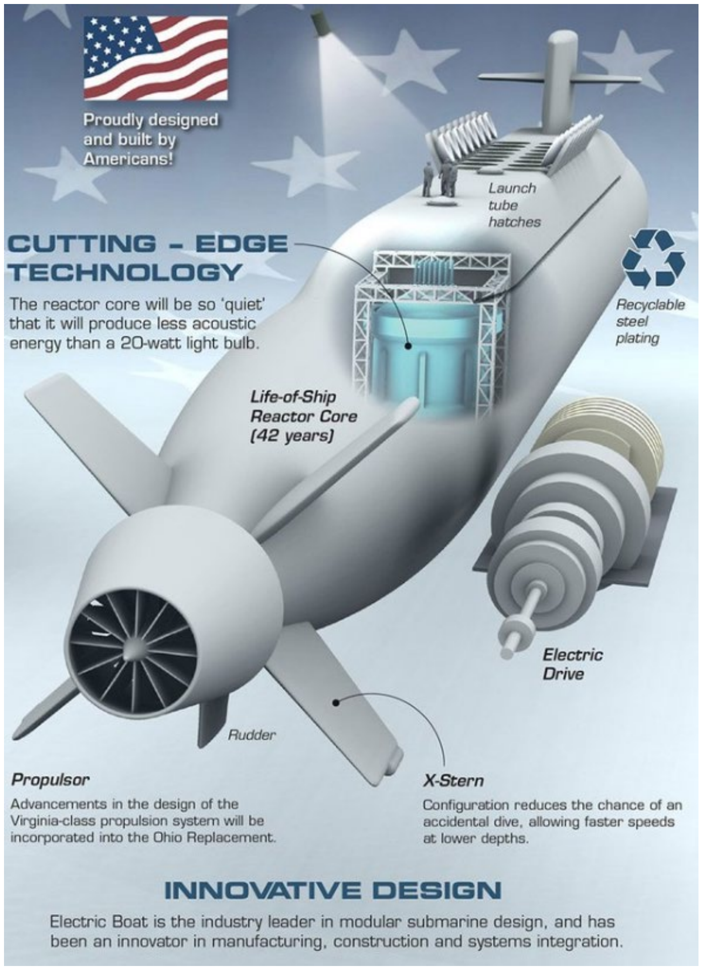

Figure 5. Cutting-edge technology on the Columbia-class submarine. Source: General Dynamics (n.d.).

D. SUMMARY

This chapter described the concept of strategic deterrence, provided a detailed description of the nuclear triad, discussed the role of SSBNs in the nuclear triad, discussed the fundamentals of SSBN operations, included an overview of the legacy of the Ohio-class SSBNs and their predecessors, and concluded with the current state of the Columbia-class submarine and anticipated improvements over the Ohio-class submarine. The information in this chapter is provided to emphasize the importance of SSBNs and why a new class of SSBN is required. Given the need for the Ohio-class SSBN replacement, the next chapter provides a literature review to discuss the major obstacles to the delivery of the Columbia-class submarine.

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III. LITERATURE REVIEW

Despite the major forward progress made on the Columbia-class submarine, delays in early construction are threatening timely delivery to the fleet (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)

In addition to the GAO report, the Congressional Research Service (CRS) published a report which provides additional “background information and potential oversight issues for Congress on the Navy’s Columbia class program” (O’Rourke, 2022, p. 2). Specifically, the CRS report details GAO, Navy, and Congressional Budget Office (CBO) perspectives on the risk of schedule delay in designing and building the leading boat, the risk of cost growth, program affordability, and industrial-base challenges (O’Rourke, 2022, p. 3).

A. GOVERNMENT ACCOUNTABILITY OFFICE REPORT

The GAO released its most recent revision of report GAO-21-257, “Columbia class submarine: delivery hinges on timely and quality materials from an atrophied supplier base” on January 14, 2021. This report describes the major obstacles that threaten schedule delays for the Columbia program office.

1. Software Issues

Electric Boat 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 3-D 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 greatly 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 January 2021, when the most recent revision of the GAO report was released, 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." Though not listed in the GAO report, the CRS report, updated in 2022, states that "the shipbuilder [did not meet] the goal for design disclosures" (O'Rourke, 2022, p. 17).

2. 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 39 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 approximately 17,000 to approximately 5,000 (p. 9). The program executive officer for the Columbia-class program, Rear Admiral Scott Pappano 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 some 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).

3. Quality Assurance Issues

However, "inexperienced workers performing complex welds" is not the only reason that Electric Boat received substandard materials for the Columbia-class submarine. 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). A strong quality assurance program is not only an industry best practice but also a GAO requirement to minimize the probability of schedule delays and inefficient use of taxpayer dollars. At this point, however, the GAO has 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 likely another major driver for schedule delays.

B. CONGRESSIONAL RESEARCH SERVICE REPORT

The CRS released its most recent revision of report R41129, "Navy Columbia (SSBN 826) class ballistic missile submarine program: background and issues for congress" on April 27, 2022. This report expands on the GAO report and provides the most up-to-date publicly available information for major issues facing the Columbia-class program office. These problems are split into two major categories: risk of schedule delay and risk of cost growth. This report encompasses the Navy and GAO perspectives on both issues.

1. Risk of Schedule Delay

The Columbia-class program office had "as little as two months of [schedule] margin" remaining according to Rear Admiral (RADM) Scott Pappano in October 2021, who was then the program executive officer (PEO) for the Columbia-class submarine as is now the PEO for strategic submarines. With so little margin remaining, clear identification of problems and prevention of future schedule slip is of the utmost importance. In addition to the problems identified by the GAO report, the CRS report adds technological risk and an aggressive production schedule as threats to schedule delay.

a. Technological Risk

The Columbia-class submarine will contain many technological upgrades over its predecessors. With each new 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). Admiral Caldwell, the director of the Naval Nuclear Propulsion Program, stated that "[the electric drive system] performed flawlessly" under "the most stressing conditions that we think we would encounter" (O'Rourke, 2022, p. 14). However, 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).

b. Aggressive Production Schedule

The lead ship of the Columbia-class is slated to be built in 84 months, approximately seven 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.

2. Risk of Cost Growth

Though the primary focus of the Columbia-class program office is delivering the new SSBNs on time, another concern addressed by the CRS report is the risk of cost overrun. 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 could jeopardize other Navy construction efforts which could affect the ability of the Navy to realize its strategic vision as it is currently planned.

a. Increasing Columbia-Class Cost Estimates

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 many reasons why the Navy may be underestimating its costs according to the CBO, the GAO assesses it is likely 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). Secondly, the GAO assessed that the Columbia-class program office 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).

As time progressed, the Navy sought to make up for these deficiencies to provide more up-to-date cost estimates. 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, even with these changes, it is important to note that accurate cost estimates are a particularly difficult challenge for any lead ship in a new class. This is primarily due to a host of unanticipated costs that are discovered during the acquisition process which cause large changes from the initial estimates. From the FY21 budget, when the first Columbia-class was first officially procured, to the most recent FY23 budget, estimated costs have been updated and steadily increasing as shown in Table 2.

Table 2. Change in estimated procurement costs since FY2021 budget (millions of then-year dollars, rounded to the nearest tenth). Source: O'Rourke (2022).

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.

These rising costs are concerning due to the impact they might have on the Navy's shipbuilding program at large. Another factor that could be resulting in increased program costs is the contract type for the first two Columbia-class submarines.

b. Contract Type

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" (Federal Acquisition Regulation, 2022). CPIF contracts can increase the probability of a cost-overrun because they transfer excess costs from the prime contractor to the government. In the case of the Columbia-class program, the likelihood of the government incurring excess costs is high because designing the lead ship in a class is always an expensive endeavor wrought with unforeseen obstacles and challenges not initially budgeted for.

c. Potential Impact on Other Navy Shipbuilding Programs

Columbia-class submarines have the potential to represent a large portion of the Navy's shipbuilding budget. Discounting the cost of the first Columbia-class submarine, which is more expensive due to including design/nonrecurring engineering costs, 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 as a whole 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. In the FY23 budget the Navy is requesting a shipbuilding budget of $27.9 billion (O'Rourke, 2022, p. 23). Assuming this budget is approved, the Columbia-class represents about 30% of the overall budget. Though how much impact receiving 30% of the allocated budget seriously affects the Navy's shipbuilding program at large is up for debate, it is important to recognize that this percentage could grow given Columbia procurement costs increases or smaller budgets.

C. SUMMARY

This chapter described the major obstacles to the delivery of the Columbia-class submarine. The GAO report focused on both describing schedule delays caused by issues with the software used to generate design enclosures and a strained supplier base working on three nuclear submarines per year as well as performance problems driven by quality assurance issues. The CRS report described issues related to both threats of additional schedule delays and cost concerns. Continued delays to the already strained Columbia-class schedule could result from the technological risk in the program or from the aggressive production schedule. Additionally, cost concerns due to increasing cost estimates for the program and the CPIF contract could affect the production of other Navy shipbuilding programs. The literature review provides the information necessary for generating a case study. The next chapter details the benefits of learning by the case study method and how to create an effective case study.

IV. CREATING A CASE STUDY

A case study is a documented, well-studied, and powerful tool that allows a student to deeply engage with the content they are working with. I chose to utilize a case study for this thesis to not only challenge readers to generate their own solutions for the delivery of the Columbia-class submarine and compare them with my own but also and more importantly to allow them to engage and learn about the problem-solving process.

A. HISTORY OF THE HARVARD CASE STUDY METHOD

Though case studies have been utilized throughout the history of academia in some form, the formal technique of analyzing a case that I employ in this thesis is derived from the Harvard case study method. The Harvard case study was pioneered in 1921 by a group of Harvard professors that aspired to create a more effective and engaging method of learning (Normand, 2017). Though changes have been made over the last century, the major process and benefits remain the same - "teach students how to apply theory in practice and how to induce theory from practice. The case study method cultivates the capacity for critical analysis, judgment, decision-making, and action" (Nohria, 2021). According to Yannis Normand, "the case method has been the most widely applied and successful teaching instrument to come out of Harvard Business School (HBS)" (2017). This thesis seeks to apply portions of this framework to a difficult acquisition challenge to generate useful solutions as well as allow students to draw on the benefits of utilizing the method.

B. BENEFITS OF THE CASE STUDY METHOD

The major benefits of the case study method are having a framework to generate useful solutions to a complex problem and also developing a host of meta-skills. Meta-skills are defined as "long-lasting abilities that allow someone to learn new things more quickly" (Nohria, 2021). Chapter VI, case study analysis and conclusions, will discuss how to execute the problem-solving framework in more detail. This section will focus on the benefits provided by analyzing cases to a student's meta-skills.

Nitin Nohria, former dean of Harvard Business School (HBS), lists seven meta-skills that develop when working with case studies: preparation, discernment, bias recognition, judgment, collaboration, curiosity, and self-confidence (2021). Reflecting on his experience at HBS, Nohria assesses that, although there may be other ways of improving these meta-skills, "under the direction of a masterful teacher, the case method can engage students and help them develop powerful meta-skills like no other form of teaching" (2021).

1. Preparation

Preparing for a case takes a significant amount of time. Students are required to probe through the provided materials to work towards a deeper level of understanding and utilize that understanding to recommend decisions on complex problems. The meta-skill of preparation is vital to members on all levels of the acquisitions community. Acquisitions programs have multi-faceted problems that cannot be solved by surface-level, shallow thinking. To best serve all major stakeholders such as warfighters and taxpayers, acquisition professionals must take the time to prepare before executing or presenting their recommended plan moving forward.

2. Discernment

Case studies create a realistic environment where students can work on their ability to discern the most important information from the extraneous details. Program managers can use the skill of discernment to focus their team. Who are the key stakeholders for the program? What are they most concerned about? Is there any important information that is missing (Nohria, 2021)? Discerning the facts that matter the most allows students and professionals to make informed decisions for all stakeholders involved in solving whatever challenges they face.

3. Bias Recognition

The acquisition workforce recruits from a diverse selection of backgrounds across the United States. Each of these employees brings their own biases with them. A Marine Corps Colonel would bring a different set of biases to acquisitions than a fresh college graduate eager to make a difference for the Department of Defense. Case studies allow students to become aware of and confront these biases which helps students prepare to avoid them in real-world problem-solving.

4. Judgment

Judgment is the skill of weighing multiple courses of action (COA) and making a logical decision. Many difficult problems appear to have multiple, equally good (or bad) decisions. Applying the skill of judgment allows the student or decision-maker to weigh certain criteria more than others based on stakeholder needs and recommend the best possible solution given the constraints. Using a logical framework to make judgments also provides the easiest method to explain the "why" behind a decision to others and increase effective communication. Criteria weighting can easily be adjusted as required based on the situation.

5. Collaboration

Case studies are designed to have multiple possible solutions. One student's judgment might not exactly reflect another's. The ability to share conclusions and work through disagreements is a crucial skill. In acquisitions, there can be a large group of diverse stakeholders. The capability of a program manager to have fruitful interactions with warfighters, the chain of command, military leaders, auditors, and in some cases, political figures greatly increases the likelihood of mission success.

6. Curiosity

Cases "expose students to lots of different situations and roles" (Nohria, 2021). One benefit of being exposed to new situations is to allow the student to think in a way they are not accustomed to. By thinking at a higher or different level, students become more well-rounded thinkers in the classroom. These new lines of thought could also inspire additional questions that, when answered, contribute to the overall growth of the case study participant. Curiosity is very important for acquisition professionals. A strong sense of curiosity could inspire decision-makers to conduct meaningful introspection for their program, re-evaluate existing processes, and ask bold questions that could result in a better product for the warfighter in a faster time and at a cheaper cost to the taxpayer.

7. Self-confidence

Making and defending decisions as an acquisitions professional requires courage. Case studies offer students the chance to practice in front of their peers in a lower-stakes and supportive environment. Building confidence in a realistic acquisition scenario empowers those in the classroom to have additional repetitions of decision-making. When these students get to the professional world, they can hopefully feel more comfortable when required to defend their position or make a decision when there are more external pressures such as the health and wellbeing of the warfighters.

C. CREATING AN EFFECTIVE CASE STUDY

A case study must be effectively written to take full advantage of the aforementioned benefits. Though there are many guides to writing a case, I chose to build my case study based on the advice of James L. Heskett, UPS Foundation Professor of Business Logistics, Emeritus, at HBS, Benson P. Shapiro, Malcolm P. McNair Professor of Marketing, emeritus, at HBS and Carin-Isabel Knoop, executive director of the case research & writing group at HBS.

Professor Heskett recommends to “skip the curveballs” and focus on the key issues (Heskett et al., 2020). Given the amount of schoolwork students need to perform regularly, it is easy to over-burden them by creating a case that requires finding a ‘hidden key’ to correctly solving the case (Heskett et al., 2020). Professor Knoop agrees with focusing on key issues and recommends “having a clear, succinct learning objective in mind” before you get started (Heskett et al., 2020), When I built my case, I decided that I want students to focus on making a decision within the boundaries of the four criteria I selected: cost, schedule, performance and technological risk.

Another guideline Professor Heskett offers is to focus on quality over quantity (Heskett et al., 2020). Professor McNair echoes a similar sentiment by suggesting the removal of all superfluous details and to “include only those important and useful details that can help students make decisions and understand key issues that the case explores" (Heskett et al., 2020). When I created my case study, I summarized the information provided in the background and literature review to only include those details that were essential to solving the case.

Lastly, Professor Shapiro recommends building a case that encourages emotional engagement (Heskett et al., 2020). Shapiro argues that "great cases revolve around points of contention on which intelligent people can hold different points of view: *what should you do? Why? How do you get it done?*" (Heskett et al., 2020). I encouraged emotional engagement by providing two compelling yet different answers to the case. Additionally, strategic deterrence lends itself to being an emotional subject- the lack of a strategic deterrent capability can amount to an existential threat.

D. SUMMARY

This chapter described a brief history of the Harvard case study method, discussed its major benefits, and provided some tips on how to generate a case study. Leveraging the advice of HBS case study experts and the information I provided in the background and literature review, I generated the following case study to allow students to exercise their decision-making abilities and other meta-skills while learning about the Columbia-class submarine and the difficulties the program office faces.

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V. CASE STUDY

A. INTRODUCTION

Admiral (ADM) Michael Gilday, Chief of Naval Operations (CNO) sat at his desk facing a difficult problem in the first quarter of 2022. As the CNO, ADM Gilday 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 carrying out his charge the CNO is consistently facing numerous difficult challenges for the Navy. However, one challenge stood out to him this particular morning: ensuring the timely delivery of the Columbia-class submarine. He had just gotten off a phone call with Rear Admiral (RADM) Scott Pappano, Program Executive Officer (PEO) SSBN, Strategic Submarines who was responsible for the Columbia-class program. RADM Pappano called to inform the CNO of the release of a new revision of the Congressional Research Service (CRS) report on the Columbia-class submarine and to provide him with 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 and as advertised would result in a nuclear strategic deterrence gap for the United States. However, with little schedule margin remaining and additional pressures to accurately report and minimize program costs, the path moving forward was unclear. What was the optimal combination of cost, schedule, and performance?

B. BACKGROUND

The Columbia-class ballistic missile nuclear submarine (SSBN) is the sea-based nuclear deterrent replacement for the Ohio-class SSBNs that have patrolled the world’s oceans for over 40 years. 12 Columbia-class SSBNs are set to replace the 14 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. Some of the most notable upgrades include a nuclear reactor that requires no mid-life refueling, an electric-drive propulsion system, an ‘x-shaped’ rudder and stern plane system, the most modern sonar suite, and the most advanced sound silencing capabilities. In addition to the major upgrades, the Columbia-class submarine will be configured to continue carrying the Trident II D-5 Submarine Launches 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 drastically reduces the risk of a delay of the first Columbia-class strategic deterrence patrol in 2031 by avoiding the acquisition of a nuclear weapon at the same time as the platform that will carry it.

Figure 6. Unarmed Trident II D-5 missile launched from a ballistic missile submarine. Source: U.S. Navy (n.d.).

Nuclear strategic deterrence is the most important mission of the Department of Defense, and the Columbia-class submarine is the most important acquisition program. As the Ohio-class submarines begin to reach their end-of-life criteria, Columbia-class submarines must be ready to replace the loss of the legacy deterrence platforms. 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 would greatly jeopardize the national security of the United States.

C. BIG "A" ACQUISITION

The CNO knew the difficulties RADM Pappano was facing. As the PEO SSBN, Strategic Submarines, RADM Pappano, like other PEOs and program managers (PMs) was responsible for managing the "triple constraint" of his program: cost, schedule, and performance. Though a seemingly simple concept, the CNO knew there was more to it than meets the eye. At most, a PEO or PM could optimize the triple constraint for two of its three variables and would be required to make concessions for the other. As an example, RADM Pappano could focus on delivering a quality submarine on time if he was able to increase the overall cost of the program. Conversely, RADM Pappano could also choose to drastically cut costs for the program.

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 System (DAS) (Moran, 2006).

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 and are written in the capability delivery document (CDD). In the case of the Columbia-class program, that need is providing a source of sea-based strategic deterrence that lasts well into the future. The PPBE process is responsible for the allocation of recourses to programs. Unlike the other two parts of Big "A" acquisition, the PPBE process is a calendar-driven system. The final portion of Big "A" acquisition is the DAS, which is an events-driven system. Operating inside of the DAS requires the PEO or PM to guide their program along one of the pathways of the Adaptive Acquisition Framework (AAF) as seen in Figure Seven. The Columbia-class submarine is a major capability acquisition that is in the engineering and manufacturing development (EMD) phase following an approved milestone B decision in 2017.

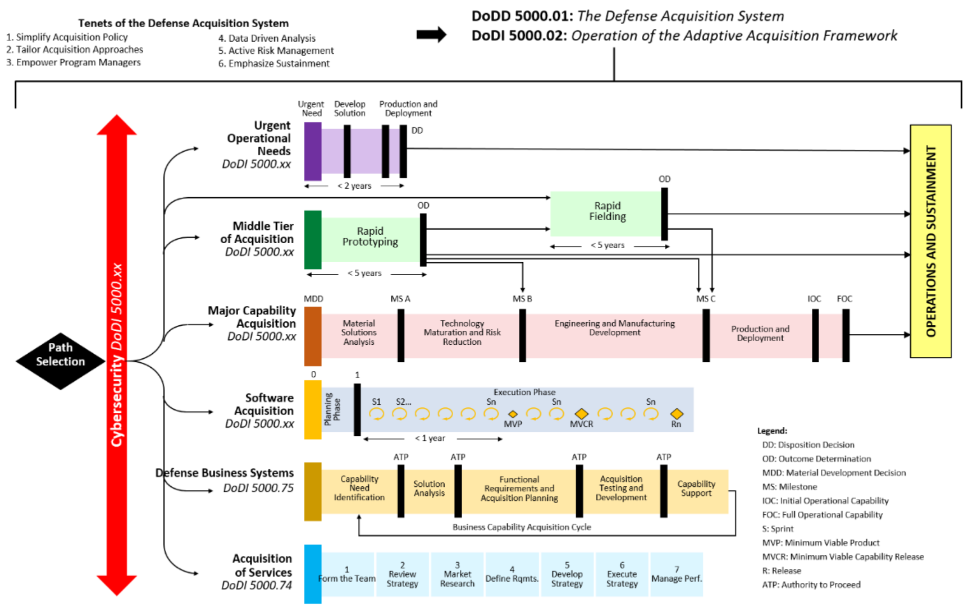

Figure 7. Adaptive acquisition framework. Source: Adaptive Acquisition Framework (n.d.).

RADM Pappano had his work cut out for him—operating within the Big "A" framework for the most important program in the country was far from an easy task. His major challenge was to find the optimal mix of cost, schedule, and performance within the Big "A" environment. Figure 8 provides a visual representation and summary of the Big "A" concepts discussed.

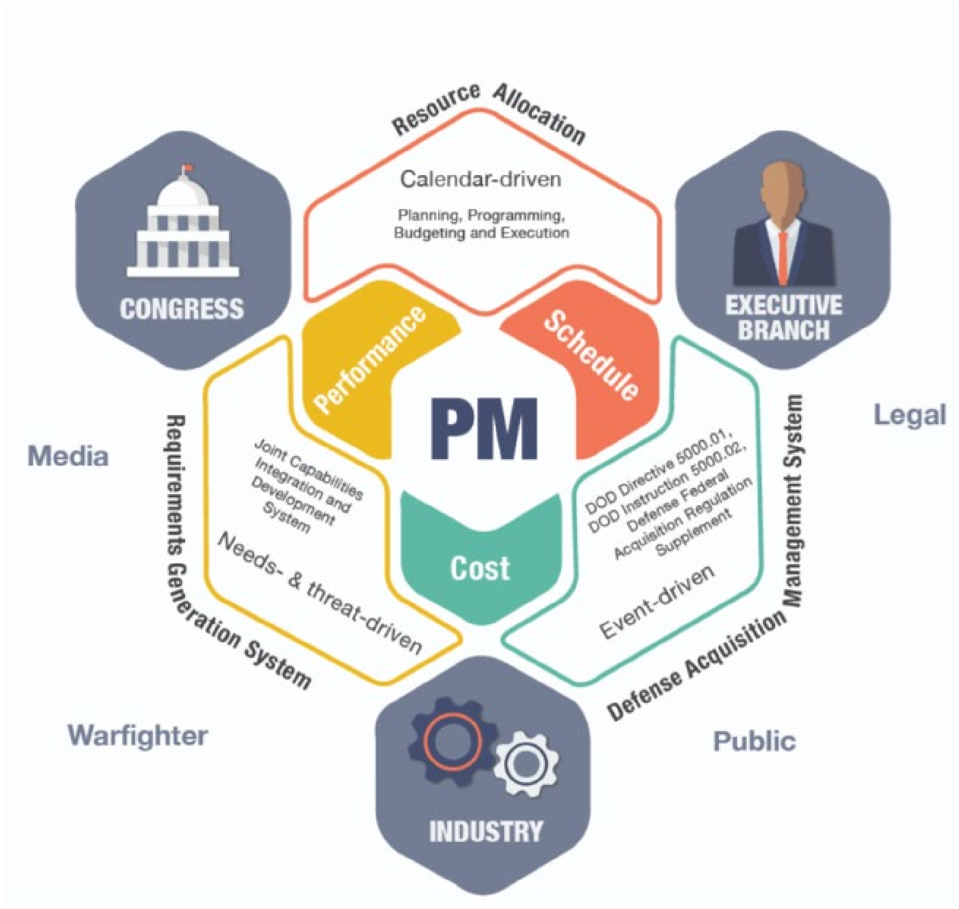

Figure 8. Big "A" acquisition. Source: Mortlock (2021).

D. COLUMBIA-CLASS ACQUISITION PROGRAM BASELINE

The current acquisition program baseline (APB) for the Columbia-class submarine was approved on 25 February 2019. An APB is developed by the Navy, approved by the milestone decision authority (MDA), and details the threshold and objective values for cost, schedule, and performance which are listed as key performance parameters (KPPs) for which the PM must manage the program. These cost, schedule, and performance goals from the current APB can be seen in Tables 3, 4, and 5 respectively.

Table 3. Cost summary. Source: *SSBN 826 Columbia-class submarine* (2019).

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 4. Schedule events. Source: *SSBN 826 Columbia-class submarine* (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	(Ch-1)
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 5. Performance characteristics. Source: *SSBN 826 Columbia-class submarine* (2019).

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	$120.2M (CY2017$) (Ch-1)
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	$7.18B (CY2017$) (Ch-2)
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

E. PROBLEMS

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

Schedule problems are one of the major issues facing the Columbia-class submarine. These schedule delays were caused in part by problems with the software used to design the submarine. The prime contractor, Electric Boat, switched to a new computer-aided software tool because the software for the previous tool was “no longer supported by the original developer” (GAO, 2021, p. 6). This new software tool, which was supposed to speed up the completion of key design products, had numerous issues which resulted in a delay in their completion. Without the required design products, the contractors could not order materials and begin construction on many parts of the submarine, pushing back the overall schedule.

The next issue which has and may continue to cause schedule delays and also affect performance is the significant strain on the submarine supplier base. In the mind of RADM Pappano, the submarine supplier base represented to most significant risk to the program (O’Rourke, 2022, p. 12). 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 pace of submarine construction has been unmatched since the beginning of the cold war with a submarine supplier base that’s approximately 70–80% of the former size (GAO, 2021, p. 9). The GAO (2021) estimated that the number of suppliers has decreased from approximately 17,000 to approximately 5,000 (p. 9). This smaller supplier base is constantly competing for parts and skilled labor. If a part is unable to be manufactured, a schedule delay could result. Additionally, due to the lack of skilled labor, there could be performance issues that lead to schedule delays. In one example, the lack of skilled labor manifested itself when a subcontractor delivered missile tubes for the common missile compartment. This resulted in a schedule delay due to the follow-on required rework.

Another problem facing the schedule of the Columbia-class program office is the technological risk associated with the new SSBN. One specific risk on the mind of the CNO which was brought to his attention by RADM Pappano is 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. Admiral Caldwell, the director of the Naval Nuclear Propulsion Program, certified that the "[the electric drive system] performed flawlessly" under "the most stressing conditions that we think we would encounter" (O'Rourke, 2022, p. 14). However, the GAO warned that "additional development and testing [is] required to demonstrate the maturity of several technologies critical to performance" (O'Rourke, 2022, p. 15-16).

As if the schedule pressures didn't put enough pressure on him, the CNO was also informed that RADM Pappano was receiving requests to improve the quality of cost estimates and overall increasing costs for the Columbia-class program. Not accounting for the first submarine which had an estimated cost of over $14 billion, each subsequent Columbia-class submarine was approximately estimated at approximately $8 billion apiece. These costs could continue to increase as the USS *Columbia* is being built on a cost-plus incentive fee (CPIF) contract. 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" (Federal Acquisition Regulation, 2022). CPIF contracts can increase the probability of a cost-overrun because they transfer excess costs from the prime contractor to the government. In the case of the Columbia-class program, the likelihood of the government incurring excess costs is high because designing the lead ship in a class is always an expensive endeavor wrought with unforeseen obstacles and challenges not initially budgeted for. This expensive program represented a large portion of the Navy's overall shipbuilding budget, and in a worst-case scenario, would put pressure on other shipbuilding programs. This had the CNO worried about achieving his goal of 355 ships by the mid-2050s.

F. POSSIBLE ACTIONS

The CNO sat and carefully pondered possible solutions. His principal challenge was to determine who the major stakeholders are, figure out what their concerns were, and discuss with RADM Pappano how to optimize the triple constraint and technological risk for the Columbia-class program in a way that best addresses the most important concerns.

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? They had already had their lives extended at least once to accommodate delays in the Columbia-class submarine. Also, would there be any willingness from other military and civilian 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 thought that another avenue that should be pursued was accelerating the development of the Columbia-class submarine. He assessed this could be accomplished by strengthening the submarine industrial base. A more robust industrial base would help to alleviate material supply issues which would assist in minimizing schedule delays. 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." However, there were many different ways to utilize the DPA Title III. 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 any other provisions that should be considered?

A final risk to schedule came from the new technologies that were being introduced on the Columbia-class. There were different opinions as to how mature the technology really is. Is conducting thorough operational testing to minimize the chance of any technical risk for major systems worth the time investment? If a flaw was discovered early, it could save large schedule delays 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 state-of-the-practice. This would likely come at the cost of performance in the competitive undersea domain, but a new line of Ohio-class submarines could certainly be created by 2031.

Each of these possible solutions will come at some increased expense. Cost is another side of the triple constraint that *could* be optimized. How important is it to minimize the cost growth of the Columbia-class submarine program? Is it worth sacrificing schedule for cost? This option would likely only be possible if the CNO was able to alleviate schedule pressure created by the need identified in the JCIDS process by modifying the schedule in the APB.

G. CONCLUSION

In order to avoid the extremely undesirable outcome, the CNO knew he had to work with RADM Pappano to make some decisions. Time was ticking.

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VI. CASE STUDY ANALYSIS AND CONCLUSIONS

A. CASE STUDY ANALYSIS

A strong acquisition case study analysis contains four vital parts: defining stakeholders, defining options and criteria, utilizing a decision matrix to make a logical decision, and presenting a final recommendation.

1. Stakeholder Analysis

The Columbia-class submarine has a variety of stakeholders. The first step is to list all of the stakeholders and denote which aspects of the triple constraint they are the most concerned about. At most, each stakeholder can only choose to prioritize up to two concerns due to the limitations of the triple constraint. I have summarized the stakeholders and their concerns in Table 6.

Table 6. Stakeholder analysis

Stakeholder	**Primary Concern(s)**
Congress	Schedule/cost
U.S. Strategic Command (STRATCOM)	Schedule/performance
Submarine warfare community	Schedule/performance
All other Navy warfare communities	Cost
Taxpayer	Cost

2. Define Options and Criteria

Given the stakeholders and their primary concerns, the next step is to define options and decision criteria. Each option presented seeks to manage some aspect of the triple constraint. To clearly define criteria, an optimal schedule provides some type of sea-based strategic deterrent asset when it is needed such that a strategic deterrence gap is avoided, an optimal performance delivers a sea-based strategic deterrent asset that has all required capabilities to operate in a modern, competitive undersea-warfare environment while performing the mission of strategic deterrence, and an optimal cost minimizes cost to the taxpayer while still providing all planned capabilities. In addition to the criteria of the triple constraint, I have added technological risk as my piece of decision criteria. An optimal technological risk represents a highly improbable chance of any new technologies failing or any legacy technology being unavailable that would delay schedule.

a. Option One – Continue Columbia-class Program, Strengthen Industrial Base and Quality Assurance Programs (Schedule and Performance Optimization)

The DPA Title III should be used to improve/expand the state of the submarine industrial base. The goal of utilizing the DPA Title III is to incentivize existing suppliers to hire new workers, improve the training programs for their current workforce, purchase new equipment or expand their facilities which can aid in the production of submarine or submarine parts, and also to attract new suppliers or sources of labor. There are multiple ways of achieving this goal. Purchase commitments could reassure existing suppliers of the future guaranteed demand for their supplies and/or labor, thereby lowering their risk (Lehman, n.d.). This would increase the likelihood a supplier would spend their money to expand capabilities to support submarine production. Knowing that the government was offering purchase commitments could attract new suppliers or sources of labor who are seeking guaranteed future work. An in-rush of new suppliers would lessen the reliance on existing suppliers, helping to lower costs for future Columbia-class SSBNs. These new suppliers could provide quality, timely materials and bring experienced workers who would increase the quality of the work performed. The greater the quality of the industrial base, the less likely the Columbia program office will have to wait for parts or conduct rework, improving the speed at which the Columbia-class submarines will be delivered.

Outside of seeking to grow the industrial base, another way to minimize the probability of schedule delays for the Columbia class submarine is to increase the thoroughness of the quality assurance program. One obstacle to conducting "intrusive" supplier audits as required by a thorough quality assurance program was COVID-19 in 2020 (O'Rourke, 2022, p. 12). However, with the pandemic slowing down in early 2021, the quality assurance program must be brought back in full force. According to the Congressional Research Service, "documents from Electric Boat indicate that standard quality assurance activities early in the Columbia program were not sufficient to manage the diminished supplier base" (2022, p. 27). If the Navy can improve its quality assurance issues there is a much greater chance of catching a quality issue before it happens saving money by avoiding rework and, most importantly, avoiding additional schedule delays.

b. Option Two – Continue Columbia-class Program, Extend the Service Life of the Ohio-class Submarines (Schedule and Performance Optimization)

Schedule pressure is driven by the strategic deterrence gap that would occur in 2031 provided that the Columbia-class submarine was not delivered on time. One method of alleviating schedule pressure is to extend the life of the Ohio-class submarines. There is no guarantee this option would be technically feasible. This does not directly solve the problem, but it could allow the Columbia program office more flexibility. Admiral Frank Caldwell, the Director of the Naval Nuclear Propulsion Program, stated that "while it's not possible to extend the entire [Ohio] class any further, we are looking at individuals hulls to see if we can gain additional months or even a few years to allow us to have greater [schedule] flexibility" (Eckstein, 2020b). The main character of the case study is the CNO who would have the ability to request an Ohio-class hull extension reevaluation.

c. Option Three – Continue Columbia-class Program, Accept Strategic Deterrence Gap (Schedule and Cost Optimization)

The Columbia program office could lessen schedule pressure and incur cost savings by not going to great lengths to deliver the Columbia-class submarine by 2031 if the civilian and military leaders of this nation were willing to accept a temporary strategic deterrence gap.

d. Option Four – Cancel Columbia-class Program, Build New Ohio-class Submarines (Technology Risk Optimization)

Ohio-class submarines have been performing the mission of strategic deterrence for years. Though they would not be as capable as what the Columbia-class promises in the undersea domain against a near-peer adversary which could affect their ability to perform the mission of strategic deterrence, Ohio-class submarines are a well-known design that contain mature technologies. Not utilizing the electric-drive propulsion alone would greatly reduce the technological risk.

3. Decision Matrix

Given the four options, I created a decision matrix to make help my final decision about the optimal choice moving forward. A decision matrix is a tool that helps to introduce a logical framework for making a choice. For each criterion the options are ranked from 1 to 4. 1 represents "the best" option in terms of that criteria whereas 4 represents "the worst." If multiple options are tied, their rankings are averaged. As an example, suppose option one is rated a 4 (the worst), option two is rated a 1 (the best), and options three and four are equal. In order to determine what ranking to list for options three and four, I would use the following equation: (2+3)/2. This would result in an average ranking of 2.5. Following ranking the criteria for each option, the rankings are summed in the 'Option Score' column. The lowest score represents the best outcome assuming all the criteria are weighted equally.

My decision matrix for options one through four can be seen in Table 7. I included my rationale for the ranking of all criteria below.

Table 7. Decision matrix

Decision Matrix (Qualitative Ranking of Options)					Option Score (Lower is Better)
Options \ Criteria	Cost	Schedule	Performance	Technological Risk	
Option One – Continue Columbia-class Program, Strengthen Industrial Base and Quality Assurance Programs	4	2.5	2	2	10.5
Option Two – Continue Columbia-class Program, Extend the Service Life of the Ohio-class Submarine	2.5	2.5	2	4	11
Option Three - Continue Columbia-class Program, Accept Strategic Deterrence Gap	2.5	4	2	3	11.5
Option Four - Cancel Columbia-class Program, Build New Ohio-class Submarines	1	1	4	1	7

a. *Cost Ranking Rationale*

I assess that option four (cancel the Columbia-class program and build new Ohio-class submarines) is likely the best option in terms of cost. Though there are costs associated with canceling the Columbia program and bringing back the production of Ohio-class submarines such as rebuilding, retraining, and refocusing the team on building a different kind of submarine, I believe that these costs would still be less than moving forward with the Columbia-class. The USS *Columbia* incorporates new technologies that have not been integrated and fully tested in all operational environments. Any issues resulting from this testing could cause significant increases in the cost of the program as engineers conduct rework. I assessed options two and three are equal in terms of cost. Each of these options continues the Columbia-class program but lessens schedule pressure by some means. By lessening schedule pressure, I conclude that significant amounts of additional funding will not be required to complete the Columbia-class submarine in time. However, option one (continue the Columbia-class program, strengthen the industrial base and quality assurance programs) will result in a significant increase in price as additional funds are utilized to increase the size and quality of the industrial base via DPA Title III, as well as fully restore and improve existing quality assurance programs.

b. *Schedule Ranking Rationale*

When it comes to delivering some type of sea-based strategic deterrent asset when it is needed such that a strategic deterrence gap is avoided, I assess that option four (cancel the Columbia-class program and build new Ohio-class submarines) presents the best choice. Though refocusing and retraining the program office and industrial base and retooling and reordering materials would take time, I assess it would take less time than completing the design, construction, and troubleshooting of the first-in-class USS *Columbia.* I ranked options one and two as the same ranking with respect to schedule because both options would be able to prevent the occurrence of a strategic gap, even though it would be achieved through different means (option one would produce a Columbia-class submarine on time, option two would extend the life of the Ohio-class submarines while the Columbia-class submarine was constructed at a slower schedule).

Option three (continue the Columbia-class program, accept strategic deterrence gap) earned the worst ranking because I defined my schedule criteria as delivering a platform that would avoid a strategic deterrence gap. Option three causes a strategic deterrence gap, and therefore it is ranked last.

c. Performance Ranking Rationale

The Columbia-class submarine represents a revolutionary platform in the undersea warfare domain. The sum of its new technologies will enable the next generation SSBN to be more efficient and stealthier than ever before and would be able to perform the mission of strategic deterrence better than the Ohio-class submarine. Even though the Columbia-class will carry the same nuclear missiles as its predecessor, the improvements in stealth technology will make it much more difficult for adversaries of the United States to find. As the capability of foreign submarines increases, their ability to locate Ohio-class submarines will also improve. The harder our SSBNs are to find, the better they can perform the mission of strategic deterrence by existing an unlocatable threat. For this reason, I ranked options one through three the same and better than option four as they would all (eventually) deliver a Columbia-class submarine.

d. Technological Risk Ranking Rationale

I ranked option four as having the least amount of technological risk. Option four (cancel Columbia-class program, build new Ohio-class submarines) would utilize proven technologies on a proven platform, lowering the technological risk. I assessed option one as the next best option for technical risk (continue Columbia-class program, strengthen industrial base and quality assurance programs). Even though options two and three also result in the construction of a Columbia-class submarine, I ranked option one higher due to the benefits gained by the improved quality assurance programs which should lower technical risk as flaws are spotted earlier and in greater amounts. Option three (continue Columbia-class program, accept strategic deterrence gap) was ranked third due to building the Columbia-class submarine without the benefits of the fully restored and improved quality assurance programs. In last place was option two (continue the Columbia-class program, extend the service life of the Ohio-class submarine) due to the risk of not being able to extend the life of the Ohio-class hulls any further.

4. Decision Matrix with Sensitivity Analysis

The decision matrix is a useful tool by itself. Following the creation of my decision matrix in Table 7, I was able to rank criteria for the given options and determine an optimal solution, assuming that all criteria were weighted equally. If this was the case, option four, canceling the Columbia-class program and building new Ohio-class submarines, would be the best option (given that my rationales for rankings were justified).

However, there are other possible conclusions that the decision matrix could provide if a sensitivity analysis is utilized. A sensitivity analysis applies weights to each criterion based on the importance of the criteria to the decision-makers. The higher the weight is, the more important the individual criterion is. Tables 8, 9, and 10 represent different outcomes in each decision matrix following various sensitivity analyses. I have weighted the criteria for each analysis based on what each stakeholder from my stakeholder analysis is interested in.

Table 8. Decision matrix with sensitivity analysis favoring performance and schedule (represents STRATCOM/ submarine warfare community interests)

Decision Matrix (Qualitative Ranking of Options)						Option Score (Lower is Better)	
Options / Criteria		Cost	Schedule	Performance	Technological Risk	Unweighted	Weighted
	Criteria Weighting	1	3	5	2		
Option One - Continue Columbia-class Program, Strengthen Industrial Base and Quality Assurance Programs	Unweighted Ranking	4	2.5	2	2	10.5	
	Weighted Ranking	4	7.5	10	4		25.5
Option Two - Continue Columbia-class Program, Extend the Service Life of the Ohio-class Submarine	Unweighted Ranking	2.5	2.5	2	4	11	
	Weighted Ranking	2.5	7.5	10	8		28
Option Three - Continue Columbia-class Program, Accept Strategic Deterrence Gap	Unweighted Ranking	2.5	4	2	3	11.5	
	Weighted Ranking	2.5	12	10	6		30.5
Option Four - Cancel Columbia-class Program, Build New Ohio-class Submarines	Unweighted Ranking	1	1	4	1	7	
	Weighted Ranking	1	3	20	2		26

Table 9. Decision matrix with sensitivity analysis favoring performance and cost (represents the interests of Congress)

Decision Matrix (Qualitative Ranking of Options)						Option Score (Lower is Better)	
Criteria / Options		Cost	Schedule	Performance	Technological Risk	Unweighted	Weighted
	Criteria Weighting	3	2	5	1		
Option One - Continue Columbia-class Program, Strengthen Industrial Base and Quality Assurance Programs	Unweighted Ranking	4	2.5	2	2	10.5	
	Weighted Ranking	12	5	10	2		29
Option Two - Continue Columbia-class Program, Extend the Service Life of the Ohio-class Submarine	Unweighted Ranking	2.5	2.5	2	4	11	
	Weighted Ranking	7.5	5	10	4		26.5
Option Three - Continue Columbia-class Program, Accept Strategic Deterrence Gap	Unweighted Ranking	2.5	4	2	3	11.5	
	Weighted Ranking	7.5	8	10	3		28.5
Option Four - Cancel Columbia-class Program, Build New Ohio-class Submarines	Unweighted Ranking	1	1	4	1	7	
	Weighted Ranking	3	2	20	1		26

Table 10. Decision matrix with sensitivity analysis favoring cost (represents all other Navy warfare communities and taxpayers interests)

Decision Matrix (Qualitative Ranking of Options)						Option Score (Lower is Better)	
Criteria / Options		Cost	Schedule	Performance	Technological Risk	Unweighted	Weighted
	Criteria Weighting	5	1	1	1		
Option One - Continue Columbia-class Program, Strengthen Industrial Base and Quality Assurance Programs	Unweighted Ranking	4	2.5	2	2	10.5	
	Weighted Ranking	20	2.5	2	2		26.5
Option Two - Continue Columbia-class Program, Extend the Service Life of the Ohio-class Submarine	Unweighted Ranking	2.5	2.5	2	4	11	
	Weighted Ranking	12.5	2.5	2	4		21
Option Three - Continue Columbia-class Program, Accept Strategic Deterrence Gap	Unweighted Ranking	2.5	4	2	3	11.5	
	Weighted Ranking	12.5	4	2	3		21.5
Option Four - Cancel Columbia-class Program, Build New Ohio-class Submarines	Unweighted Ranking	1	1	4	1	7	
	Weighted Ranking	5	1	4	1		11

5. Conclusion

The correct answer for the CNO lies in how he and his team weight the criteria. Though there are numerous possible weightings, I recommend focusing on a combination favoring the weighting of performance and schedule and selecting option one: continue the Columbia-class program while strengthening the industrial base and quality assurance programs.

Building the new Ohio-class submarines would result in a quicker and cheaper path moving forward to avoid the impending strategic deterrence gap. However, Ohio-class submarines are losing their edge in the undersea domain as the capability of adversarial submarines increases daily. In order to maintain a useful sea-based strategic deterrent platform, I consider it important to complete the technologically advanced Columbia-class as designed.

I also recommend prioritizing schedule over cost due to the importance of avoiding a strategic deterrence gap. Though the Congressional Research Service mentioned the potential impact of the Columbia-class submarine program on other shipbuilding programs due to the percentage of the shipbuilding budget it represented, this should not be a primary consideration. Strategic deterrence is the number one mission of the Department of Defense. If the shipbuilding budget becomes a concern, the Navy should request a larger budget or forgo building the non-SSBN platforms in the short run for the sake of the greater national security picture.

Lastly, incurring higher costs to strengthen the submarine industrial base and accompanying quality assurance program will also not only benefit the first Columbia-class submarine but will have far-reaching effects on creating and maintaining the submarine force of the future for the United States Navy. At the end of the day, what is most important is the preservation of the American way of life and the safety of its people. No cost is too great for such a precious mission.

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