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LEARNING FROM EXPERIENCE

VOLUME II

Lessons from the U.S. Navy's *Ohio*, *Seawolf*, and *Virginia* Submarine Programs

Prepared for the United States Navy

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Summary

To design and construct nuclear-powered submarines, modern navies and shipbuilders need personnel and organizations that possess unique and specialized skills and expertise. These vessels are among the most complex systems that countries produce, and the technical personnel, designers, construction tradesmen, and program managers who work on them represent pools of knowledge that take years to collect and that cannot be replicated easily or quickly.

In years past, the pace of construction on replacement submarines was quick enough in most countries that key technical and management personnel in submarine programs were able both to work on a stream of successive submarines and to pass their knowledge on to personnel who followed in their footsteps. Individuals who participated in one program gained experience to be leaders or intellectual resources in following programs.

But two events have coalesced in recent years to complicate such transfers of knowledge: Defense budgets have become constrained, and the operational lives of submarines have lengthened as the vessels' production and maintenance procedures have benefited from continuous process improvements and as navies have changed how they operate the vessels. The result is that the pace at which submarines are being replaced is likely to slow, creating significant time gaps between successive programs and far fewer opportunities for veteran personnel to pass on their knowledge to succeeding generations of submarine workers and program managers.

Recognizing the importance of documenting and imparting experiences from past submarine programs, the U.S. Navy's Program

Executive Officer (PEO) for Submarines asked the RAND Corporation to develop a set of lessons learned from previous submarine programs that could help inform future program managers. The RAND project team focused on the *Ohio, Seawolf,* and *Virginia* programs; it derived lessons from previous reports[1] on the three programs and from numerous interviews that the team conducted with past submarine program managers and submarine personnel at the two shipyards that build U.S. nuclear submarines—General Dynamics Electric Boat in Groton, Connecticut, and Huntington Ingalls Industries–Newport News Shipbuilding, in Virginia.[2]

RAND's search for lessons also involved reviewing the history of U.S. nuclear submarines from the *Nautilus*, launched in 1955, through today's *Virginia* program; investigating how operational requirements were set for the *Ohio, Seawolf,* and *Virginia* classes; exploring the acquisition, contracting, design, and build processes that the three programs employed; and assessing the plans and activities surrounding integrated logistics support for those submarine classes.

Most of the lessons that RAND identified are managerial. The project team looked for instructive aspects of how the *Ohio*, *Seawolf,* and *Virginia* programs were managed, issues that affected management decisions, and the outcomes of those decisions. At times, it was difficult for the team to judge the "success" or the "failure" of program decisions. Views change during the conduct of a program and are based on the perspective of individuals. The important point is that the decisions were not necessarily "good" or "bad." Rather, they were or were not fully informed by knowledge of the risks and consequences.

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[1] For example, see Polmar and Moore, 2004; Schumacher, 1987, 1988a, and 1988b; and multiple reports from the United States Government Accountability Office (GAO). The full set of reports is listed in the Bibliography and spans research from 1980 through 2008.

[2] On March 31, 2011, Northrop Grumman spun off its shipbuilding division. The new organization is named Huntington Ingalls Industries. Since January 2008, Northrop Grumman Shipbuilding had been the name of the submarine shipbuilding facility at Newport News, Virginia. It was known as Northrop Grumman Newport News from 2001 until 2008, as Newport News Shipbuilding from 1996 until 2001, and as Newport News and Dry Dock Company before then. For simplicity's sake, we refer to the General Dynamics facility as Electric Boat (or EB) and to the Virginia shipbuilding facility as Newport News.

In some cases, the RAND team identified lessons that have not really been learned. In other cases, the team identified lessons that have been learned but forgotten (or ignored). Since cost is typically the metric for judging program success, the majority of the lessons focus on controlling program costs.

Three Submarine Programs in Perspective

The *Ohio* and *Seawolf* programs began in a period of heightened tensions between the United States and the Soviet Union, each pushing technology and force structures in an attempt to gain an advantage over the other. The end of the Cold War brought a change in operational focus, from countering the Soviet threat in waters around the globe to the world of terrorism and the need to operate in the littorals. This new operational environment is the one that the *Virginia* program has faced.

Available budgets for nuclear submarines mirrored this change in operational focus. The end of the Cold War brought a call for a "peace dividend" and a reduction in force structures. The Navy's force dropped from more than 100 submarines at the end of the *Los Angeles* program to approximately half that number today.[3] That drop in force structure coincided with turmoil in the industrial base as the large-procurement years of the *Los Angeles*–class submarines ended and the competition and rivalry between Electric Boat and Newport News evolved into a partnership on the *Virginia* program.[4]

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3 The *Los Angeles* class had been conceived in the mid-1960s to operate with a carrier battle group to gain an attack position against Soviet submarines capable of achieving high speeds when submerged. It was designed when the U.S. Navy had a mid-ocean strategy and chose to avoid offensive operations in the Barents Sea and Sea of Okhotsk, where Soviet nuclear ballistic missile submarines might patrol.

4 Both shipyards had large workforces at the start of the *Ohio* program. Workforce demands at both shipyards dropped significantly with the termination of the *Seawolf* program. Newport News was able to sustain a fairly large workforce to support new aircraft carrier construction and the mid-life reactor refuelings and major repair of in-service carriers. However, with submarines as its only product line, EB was forced to remake itself and significantly

All three submarine programs had tenuous beginnings. Each experienced cost overruns and schedule delays in the construction of its first-of-class submarine. The *Ohio* and *Virginia* programs made corrections, and both are viewed as generally successful. *Seawolf*, likely due to the changing threat and budgetary environment, was terminated before changes could be made to correct early missteps.

An overarching lesson from the three programs is the importance of program stability. Stability applies in many areas—funding consistency, a long-term build strategy, fixed operational requirements, program management, and an integrated partnership between the Navy and the shipbuilders. Program stability is not sufficient for program success, but it is certainly a necessary attribute that greatly contributes to the success of a program. The lessons that follow largely address ways to achieve program stability.

The *Ohio* Program

The *Ohio* class was an evolutionary enhancement of the Poseidon-carrying ballistic missile submarine. As the largest submarine then built in the United States, it carried 24 missiles. The ship had the same basic compartment layout as the Polaris/Poseidon–equipped submarines that preceded it. However, it had a larger missile capacity and hull diameter, which provided the option to design better living arrangements for the 165-man crew. Overall, its missile system and ship designs were generally conservative and avoided radical new technologies.

Although the Navy was concerned with various platform capability features, the *Ohio*-class submarine was ultimately designed to support an overall nuclear ballistic missile submarine (SSBN) operational availability. To that end, an integrated logistics system was designed along with the ship; two bases, at Kings Bay, Georgia, and Bangor, Washington, were optimized to support crew training and submarine logistics requirements. In addition, the *Ohio* class was designed with redundancies in its systems and with standardized equipment and installed spares, all of which helped ensure overall system reliability.

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reduce its workforce in order to survive. Once heated rivals, the two shipyards now partner equally in the construction of the *Virginia*-class boats.

The *Ohio*-class program followed the same strategy as earlier nuclear submarine programs: minimizing technical risks by adopting the best technologies available at the time while pushing technology boundaries in only a few select areas. The program proceeded with few technical problems and is largely considered a success. It benefited from a robust industrial base and ample funding during a period of increasing defense spending intended to counter a growing Soviet threat.

The *Seawolf* Program

When the Soviets started to field improved submarines in the 1970s, the United States began to consider the design of the successor to the *Los Angeles* class.[5] Early concepts for an attack submarine focused on a number of smaller, less-expensive designs, including improving the capability of the *Los Angeles* class.[6] However, in 1981 as the new Reagan administration ushered in an era of expanded Cold War defense spending and a new maritime strategy, it soon became clear that the *Los Angeles*–class design margins were not adequate to absorb the upgrades that would be required.

In the new strategic and budgetary environment, the initial concept for a more affordable and less capable platform was set aside in favor of a more advanced platform that would both challenge the Soviet antisubmarine warfare (ASW) advantage and meet the needs of the new maritime strategy.[7]

The *Seawolf* program was initiated in 1982 with early concept development. A special naval study group was established to assess future threats and conduct technology feasibility studies. The *Seawolf*'s primary mission would be to hunt down and track Soviet ballistic missile submarines. The priorities in the development of the *Seawolf*'s

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5 By the end of the 1970s, two decades of steady Soviet advances had resulted in the *Los Angeles* class losing some of its antisubmarine warfare advantage.

6 Polmar and Moore, 2004, p. 172.

7 The new maritime strategy served to underpin a 600-ship navy and the operational objectives of the fleet. The U.S. Navy wanted to counter the Soviet submarine fleet as far forward as possible, in the sea-denial and sea-control zones. At the outbreak of hostilities, U.S. submarines would now be expected to operate far forward both in the northwest Pacific and the northeast Atlantic. Hattendorf and Swartz, 2008, pp. 74–82.

operational requirements were increased stealth (acoustic silencing) and an improved combat system. Additional mission areas included anti-surface warfare, strike warfare, surveillance, and mine warfare.

These operational capabilities required significant advances in several technology areas. Reduced quieting, higher speeds, deeper diving depths, and larger payloads not only contributed to a large submarine but one that pushed current design limits. The *Seawolf* would require a new reactor, propulsion system, and combat system as well as the use of new steel. In many ways, the program deviated from one of the basic tenets of previous programs—limit the number of new technologies for a new class of submarines. But these multiple advances in technology were deemed necessary to meet the increasing capabilities of Soviet submarines.

The *Virginia* Program

The *Virginia*-class attack submarine was developed in the early 1990s as the successor to the *Los Angeles* and *Seawolf* classes. These classes had two things in common: Their roots were in the Cold War and, for different reasons, each had experienced unanticipated cost escalation during the construction programs. By the late 1980s, the *Los Angeles* class was in full production while the *Seawolf* program was beginning construction.

With the end of the Cold War and with growing concerns over the cost of nuclear submarines, the Navy and the shipbuilders took a different approach with the *Virginia* program. They realized that designing and building a lower-cost submarine that responded to the new threat environment was imperative for the survival of the submarine program and, to a large extent, to the nuclear submarine industrial base. Having learned from the *Seawolf* program and remembering the lessons from earlier programs, the *Virginia* program sought to reduce risks by using the best technologies available while constraining the development of new technologies.

Some of the *Virginia* lessons mirror those of the *Ohio* and *Seawolf*: Use a single design/build organization; have an appropriate level of design complete before construction starts; obtain congressional and

Department of Defense (DoD) support for the program; and maximize the degree of modular construction to reduce build costs.

Top-Level Strategic Lessons from the Three Programs

Top-level strategic lessons are global in nature and span all programs that design and build new platforms or support the U.S. Navy submarine force. They are appropriate for the PEO for Submarines and for senior U.S. Navy management. These strategic lessons address the overall management of the nuclear submarine force and of the industrial base and include the following:

- *Have experienced technical and programmatic leadership at the helm and develop strategies to grow knowledgeable and experienced managerial, oversight, and technical support personnel.* The Navy must continue to grow the right levels of expertise in the right people, sending them to various operations- and acquisition-related positions as well as providing appropriate education in the academic community. It is critical that the Navy identify the most promising junior officers for future management positions and provide them with learning experiences. Equally important is the civilian leadership in the various Navy technical organizations and laboratories and in the private sector.
- *Take a long-term, strategic view of the submarine force and the industrial base.* A new submarine development program produces more than a strategic military asset; it also contributes to domestic economic goals and is one part of a long-range operational and industrial base strategy. Technologies change, new capabilities are needed, and new threats emerge and evolve. These future evolutions require maintaining a technology/capability edge and updating existing platforms with new technologies and new capa-

bilities.[8] The technical community[9] and the industrial base must be sustained so they can provide the required capabilities when needed.

Lessons in Supporting and Managing the Three Programs

Future program managers must "manage" from several perspectives. They must interact with shipyards and vendors. They must understand technologies and how they successfully support the program. And they have to manage the expectations of higher-level organizations (the PEO, senior Navy leadership, and Congress). A strong management team is important for program success. Important lessons here include the following:

- *Ensure that the program is adequately supported by the Navy, the government, the scientific community, and the public.* Support must be both external to the program and internal within the Navy and submarine community. Political support is most important for the advancement of a new acquisition program. Support also must come from within the Navy.
- *Ensure that the program is open and transparent.* Full disclosure during the program is necessary to obtain the support of the Office of the Secretary of Defense (OSD), Congress, industry, and the public. In this regard, a good media management program is necessary. Bad press greatly and negatively affects the program. Effective communications must be proactive, not reactive, when briefing the Navy leadership, OSD, Congress, the media, academia, and others.

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8 The improved *Los Angeles* class, the conversion of the *Ohio*-class SSBNs to nuclear cruise missile submarines (SSGNs), and the construction of the USS *Jimmy Carter* are three examples of how original designs were modified for new missions and capabilities. At some point, however, new classes of submarines must be designed and constructed.

9 This includes the Navy's engineering directorates and the laboratories, test centers, and centers of excellence that support nuclear submarines.

- *Involve appropriate organizations, commands, and personnel from the beginning.* The program and the Navy must be informed customers supported by adequate technical, operational, and management expertise.[10]

Lessons from the Three Programs in Setting Operational Requirements

Decisions made very early regarding the desired operational performance of the new submarine influence the technology risk for the program and its likelihood of success. The operational requirements for the platform are translated to performance specifications that lead to technology choices to achieve the desired performance. The operational requirements, especially the desired operational availability, also affect integrated logistics support (ILS) planning. Important lessons here include the following:

- *Clearly analyze and state system requirements as a mix of key performance requirements and technical standards.* The requirements set during the contract should remain as fixed as possible for the extent of the design period. The Navy should control to the degree possible any requirements growth except where absolutely necessary. Operational requirements and technologies will change over time, resulting in major modifications during a submarine's operational life. When setting the requirements for different submarine systems, programs must understand the current and

[10] In addition to the technical community, the program office must involve operators, builders, and maintainers from the beginning of the program. The program manager should plan on spending the time necessary to ensure that the program philosophy and underlying principles (cost control, low technology risk, for example) are clear to all participants and emplaced at all levels. In addition, the program manager should be empowered with required decisionmaking authority (e.g., change control).

emerging technologies in those systems, how requirements might change in the future, and the trade-offs between costs and risks.[11]

- *Understand the current state of technology as it applies to the program and how the platform's operational requirements affect technology risks and costs.* Desired operational performance will drive the characteristics of the platform and the technologies needed to achieve the performance goals. Program managers must be supported by a technical community that completely understands the technologies that are important to the program, where they exist, and which ones must be significantly advanced. Relying too heavily on significant advances in technology will lead to risks in achieving the desired operational capabilities.[12]
- *Understand that operational requirements must also specify how to test for the achievement of that requirement*. Although it is often difficult to plan tests early in a program, it is necessary to ensure all parties agree on the processes to measure how the performance of the platform meets operational capability objectives.

Lessons from the Three Programs in Establishing an Acquisition and Contracting Environment

Establishing an open and fair acquisition and contract environment is another important aspect of any program. Good decisions here—the organizations that will be involved in designing and building the

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[11] The *Ohio* program faced such a trade-off when setting the number and size of the missile tubes. More and bigger tubes would result in a larger submarine. Working closely with the Strategic Systems Program Office, the *Ohio* program set a requirement for a missile tube with a larger diameter than needed for the C4 missile. This decision resulted in a relatively smooth transition as the last eight submarines in the *Ohio* class were specifically built to carry the D5 missile. A similar decision during the *Seawolf* program led to a less-favorable outcome. The *Seawolf* design included eight torpedo tubes each 26.5 inches in diameter versus the 21-inch tubes on previous classes. These larger tubes, in combination with a larger weapon load, led to a much larger pressure hull than on previous classes of attack submarines.

[12] The developmental platform and the developmental combat system in the *Seawolf* led to a high degree of risk. Backing off requirements slightly, especially with the combat system, could have significantly reduced those risks.

new submarine, the type of contract, the specifics within the contract (including incentives), the decisionmaking process to employ when issues arise, and the payment schedule—will resonate throughout the life of the program. Key lessons for establishing an effective acquisition and contracting environment include the following:

- *Consider a single integrated design/construction contract with the prime.* Having a single firm complete the detailed design and build of the submarine helps to integrate the two processes and reduces confusion and misinterpretations.[13] Even with a single contract for design and build of the first-of-class, the lead ship should be priced only when the detailed design is sufficiently complete for both the shipbuilder and the Navy to have enough knowledge to estimate realistic costs.
- *Use a contract structure that has provisions to handle program risks.* While the Navy can try to place all risk on a contractor through use of a fixed-price contract, the Navy ultimately holds all program risk. It is far better to structure a contract that holds the contractor responsible for risks under its control (labor rates, productivity, materiel costs, etc.) and holds the Navy responsible for risks beyond the contractor's control (inflation, changing requirements, changes in law, and so forth).[14]

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[13] The *Ohio* program had one organization, EB, design and build the submarines, but entered into separate contracts with different EB divisions to design and build the first-of-class. This led to schedule delays and cost growth to reconcile differences between the different contracts. The *Seawolf* program had the shipbuilders each design portions of the ship with competition for building the first-of-class. Again, there were significant problems with this approach. The *Virginia* program involves a single design/build prime contractor, with Newport News serving as a major subcontractor. This arrangement, plus other initiatives, has resulted in a largely successful program.

[14] The lead ship contracts for *Ohio* and *Seawolf* were both fixed-price, incentive-type contracts. Both had escalation provisions that covered the effects of inflation up to ceiling price and up to the contract delivery date without penalty. Both had substantially larger spreads from target cost to ceiling price than early *Los Angeles*–class contracts possessed. The *Virginia* program took a different approach. Rather than providing the detailed design drawings as government furnished information to the construction shipyard, *Virginia* added cost-plus-incentive-fee construction line items for the lead ship to the original cost-plus design contract.

- *Develop a timely decisionmaking process to minimize and manage changes.* Changes invariably occur during any program. They may crop up in the desired performance of the platform, in the systems and equipment used to achieve performance, in the schedule, or in the responsibilities of the organizations involved in designing, building, and testing the platform. Changes may affect cost, schedule, or capability. Management structures must be in place to deal with any of the contract changes that are proposed during the program.
- *Establish an agreed-upon tracking mechanism and payment schedule*. It is important that a program have an effective system for tracking progress and costs that involves all appropriate organizations—the Navy, the program office, the SUPSHIP, and the contractor. This system must thoroughly address all the appropriate issues and their impact on cost, schedule, and performance. The payment schedule should be tied to clearly defined and meaningful milestones.

Lessons in Designing and Building the Three Programs' Submarines

It is important that all the right organizations—designers, builders, operators, maintainers, and the technical community—are involved throughout a program, so that they understand how operational requirements affect design and construction and can plan for the appropriate testing of the systems and platform to ensure that requirements are met. To some degree, lessons for the design and build process overlap lessons that emerged from programs' earlier stages:

- *Involve builders, maintainers, operators, and the technical community in the design process.* Design/build should go further than merely involving builders in the design process. It is important to think of the design team as a collaboration of submarine draftsmen and design engineers with inputs from those who must build to the design, operate the submarine, and maintain it. This col-

laboration should extend throughout the duration of the design program. However, throughout the process, it is important to keep in mind that the cost-effectiveness of the submarine's post-delivery or ILS period is the true design and construction target.
- *Design for removal and replacement of equipment*. Adequate access paths and removal hatches should be included in the design to facilitate removing and replacing damaged or obsolete equipment. For command, control, communications, computing, and intelligence (C4I) equipment, modularity and interoperability should be incorporated into the design.
- *Complete the majority of the design drawings before the start of construction.* It is far better to delay construction to ensure the design is largely complete rather than risk the costly rework and changes typically resulting from an immature design. A good rule of thumb is to have the arrangements 100 percent complete and the overall design approximately 80 percent or more complete when construction begins.
- *Conduct a thorough and adequate test program*. Testing should involve the design and build organization(s) as well as the technical community and the Navy.

Lessons from the Three Programs in Planning for Integrated Logistics Support

Operating and supporting new submarines after they enter service account for the vast majority of their total ownership costs. Therefore, it is imperative to establish an ILS plan for the new submarines. Important lessons here include the following:

- *Establish a strategic plan for ILS during the design phase.* Such a plan must be put in place early in the program. Personnel from organizations responsible for maintaining the submarine should be involved in the design process. Additionally, the submarine's concept of operations must recognize that the vessel will require

time for preventive and corrective maintenance and for equipment modernizations.
- *Establish a planning-yard function and develop a maintenance and reliability database*. A planning-yard function to track maintenance and establish future workloads is important to ensure the right maintenance is done at the right times.
- *Plan for crew training and transition of the fleet.* The ILS plan must also include the when, where, and who for training activities, and the transition of personnel to the new submarine class. Typically, the crew assigned to a submarine during construction validates operating and casualty procedures and instructions, functions as a system and equipment validation organization for the Navy, and serves as the ship's trials and test operator.