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Sustaining U.S. Nuclear Submarine Design Capabilities

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Summary

For the first time since the advent of the nuclear-powered submarine, no new submarine design is under way or about to get under way following the winding down of the current effort (for the *Virginia* class, now in production). This is a matter of some concern, because submarine design is a large and complex undertaking that requires skills developed over many years that are not readily exercised in other domains. The erosion of the submarine design base—at Electric Boat (EB) and Northrop Grumman Newport News (NGNN), the two shipyards that perform the majority of a new submarine design, at the suppliers to the shipyards, and at the Navy itself—may lead to the loss of the required skills before a new design does get under way, perhaps in another six to eight years. This skill loss could result in schedule delays to allow for retraining, with consequent higher program costs and potential risks to system performance and safety. This raises the question of whether some action should be taken to sustain a portion of the design workforce over the gap in demand.

In view of these potential problems and the postulated solution, we sought to answer the following questions:

- How much of the submarine design workforce at the shipyards would need to be sustained for the least-cost transition to the next design? What are the implications of different approaches to allocating the workload?
- To what extent is the shipyard supplier base also at risk?
- How will the Navy's own design skills be affected by a gap, and how easily might they be recovered?

- Taking all answers to the preceding questions into account, what steps should the Navy take in the near future?

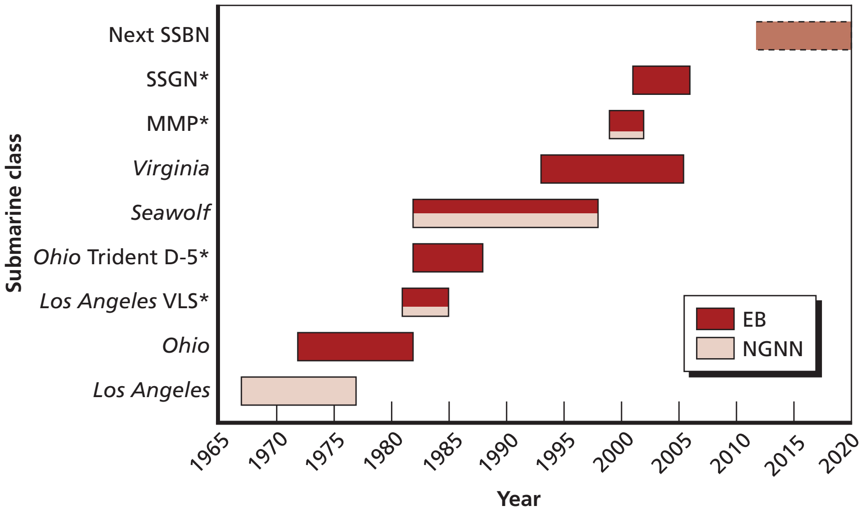
We take up each of these questions in order below. First, however, by way of background, we give a brief overview of the submarine design process and describe our approach to analyzing the problem at the shipyards (which has implications for the other design resources).

The Submarine Design Process

The early years of nuclear submarine design were marked by experimentation. A new design was undertaken even before work had finished on the previous one, and few boats were built to the same design. As the Navy and the builders gained experience and winnowed the spectrum of alternative approaches to submarine design, some stability was achieved. The *Sturgeon* class, the first of which was commissioned in 1966, extended to 37 boats. Still, the evolution of the Soviet threat required the introduction of new designs in response (see Figure S.1). The *Los Angeles* class was introduced to service in 1976 and went through two additional "flights," or significant design updates, over the next 20 years. In the post–Cold War era, changes in the threat are still recognized in submarine design: Some ballistic-missile-carrying boats of the *Ohio* class have been partially redesigned to carry guided missiles, and more attention is being paid to submarines' special-forces transport and support function. New designs, though, are largely being driven by the need to replace older boats that are wearing out. At present no such need exists, and for the first time since the advent of nuclear power, no new submarine design is on the drawing board, and, according to current Navy plans, none will be for several years.

Submarine design is currently broken down into a set of "product areas"—requirements, arrangement, mock-up, etc.—which are somewhat like work phases but which are allowed some temporal overlap. This overlapping sequence of product areas is developed for each of eight "modules"—habitability, propulsion, sail, etc. Clearly, there is a need for designers and engineers skilled in areas that do not always replicate those common to other ships. In addition, experience peculiar

Figure S.1
Overlapping U.S. Submarine Design Efforts Are Giving Way to a Gap in Demand



*Major modification to an exsiting class.
RAND *MG608-S.1*

to submarine design must be applied to ensure that all modules will be integrated appropriately.

For the purpose of our analysis, we categorized these skills in a hierarchy. Following industry analyses, we group the hundreds of skills necessary to design a nuclear submarine into 16 skill categories.

Framing the Analysis

To understand submarine design demand and supply relationships and the costs and benefits of different approaches to managing the design workforce, we categorize the available choices into two broad approaches—"doing nothing" and "doing something." Under the first approach, the prime contractors would adjust their workforce to meet known demands only. In the second, they would sustain a number of designers and engineers above known demands to serve as a foundation to rebuild the workforce for a new design effort.

The first step in analyzing the two approaches is to predict the demand for the next submarine design and its timing. We start with the known demands—the design work "on the books" that involves both support to construction efforts on in-service submarines and to any new design efforts for surface ships, such as the CVN 78 class of aircraft carriers, or for major modifications to the *Virginia* class. We then estimate when a new design effort might begin, how long it would take, and the magnitude of the workload demand. Using the current 30-year shipbuilding plan as a guide and assuming the next design effort would be similar to that of the *Virginia* class, our baseline case assumes the start of a new nuclear-powered ballistic-missile submarine (SSBN) design in 2014 that will last 15 years and require approximately 35 million man-hours of design and engineering effort. Because of the uncertainties in such a projection, we examine the sensitivity of our results to different start dates, durations, and workloads.[2]

The 2014 design start date has the virtue that the SSBN design effort will wind down about the time the design of a replacement for the *Virginia* class will be ramping up. Such a long-term view should be part of the submarine acquisition planning process, because a skilled workforce must be managed with the long view in mind. If the SSBN design were delayed by four or five years, it would overlap too much with the next nuclear-powered attack submarine (SSN) design. If it started much earlier than 2014, the current gap in demand could be replaced by a gap following the SSBN design.

Given a predicted demand, the next step in the analysis is to estimate how much the different "do-nothing" and "do-something" strategies will cost. Costs for different workforce drawdown and buildup profiles vary because of termination costs and hiring and training costs. There could also be delays associated with a less efficient workforce. This all adds up to different workload-accomplishment efficiencies for different labor supply profiles. RAND has previously quantified the costs of production gaps; however, that research was focused on production workers. For design workers, we would expect, on the one hand, lower penalties from lost learning because there is an inherent novelty to each succeeding design effort, but on the other hand, higher

[2] Note there is a unique "do-nothing" case for each combination of start date, design workload, design duration, and shipyard.

penalties for the potential loss of expertise, which should take longer to accumulate for design than for production. Productivity losses, along with training, other hiring, and termination costs, are all estimated in a workforce simulation model that we developed. Both shipyards provided data for estimating these productivity losses and costs.

The following caveats apply to the results of our analysis:

- Our model does not produce budget-quality cost estimates.
- All costs are estimates subject to estimating errors associated with future uncertainties.
- Workforce-related model inputs are based on data received from EB and NGNN.
- We assumed that both shipyards currently have the critical skills and proficiency necessary for submarine design.

Impact of Different Policies for Managing Design Resources

The model indicates that, if the next SSBN is designed at EB and the "do nothing" approach is adopted, the design effort will take about three years longer than our nominal assumption of 15 years. Sustaining a workforce above the level needed to meet demand would cut back the increase in design duration. If 800 extra people could be sustained, there would be no increase. Those extra people cost money, but they also save money by precluding the extra work associated with the schedule delay and with workforce transition costs (termination, hiring, and training). The net cost is least when 800 people are sustained: That cost is about 10 percent less than what the "do nothing" approach would cost. Doing the same analysis for NGNN indicates that 1,050 designers and engineers should be sustained and that doing so would save 36 percent relative to the "do nothing" design cost.

The least-cost workforce to sustain is relatively insensitive to the start date but somewhat more sensitive to the total workload (see Table S.1). If the latter were to be 30 percent higher or lower than that for the *Virginia* class, the least expensive workforce would increase or decrease responsively—by 20 to 30 percent for most start dates at EB or NGNN. At the *Virginia*-class workload, the total cost would increase with later start dates (longer gaps) and decrease with earlier dates. The percentage saved relative to the "do nothing" approach would also be higher with higher workloads and later start dates and lower with lower workloads and earlier dates. At the expected 2014 start date, however, the sensitivity of percentage savings to workload would be small. At the expected workload level, the sensitivity to start date would be large in the later half of the range at NGNN and in the early half at EB.

So far, we have been assuming that an early start date would be followed by our assumed 15-year design period. However, the design effort might be stretched to 20 years. That would have the benefit of filling the current design gap without creating another once the SSBN effort is complete. That is, the workforce sustained during the gap would be engaged in productive activity toward design of the new SSBN class. This is reflected in the savings: Stretching the design period results in an additional 17 percent savings relative to the 15-year cost at EB, and 22 percent at NGNN. For a given workload, these 20-year-design alternatives cost the least.

Table S.1
Results for Different Design Workloads and Start Dates

	Results for Workloads Ranging from 30% Below to 30% Above *Virginia*-Class Design Workload, for Start Dates of		
	2009	**2014**	**2018**
EB			
Minimum-cost workforce to sustain	800–1,150	550–1,000	550–1,000
Labor cost savings relative to "doing nothing" (%)	0–14	10–14	28–31
NGNN			
Minimum-cost workforce to sustain	850–1,400	700–1,200	700–1,200
Labor cost savings relative to "doing nothing" (%)	2–17	37–42	41–46

NOTE: All savings are relative to doing nothing prior to the start date assumed and for the workload assumed.

The Navy might consider it advantageous to split the design work between EB and NGNN rather than retain design expertise at only one firm. If the work is evenly split between EB and NGNN, the cost is a little higher than doing the work at one yard, even without taking into account any of the inefficiencies involved in sharing the work. A 25 percent penalty for such inefficiencies might not be an unreasonable estimate, and the cost would increase accordingly.

Finally, optimistic and pessimistic scenarios help to test how sensitive our results would be to variations in some of the parameters associated with the workforce: productivity, attrition, and hiring rate. The optimistic scenario has higher productivity, a greater hiring rate, and lower attrition, and the pessimistic scenario varies these parameters in the opposite direction. These variations are consistent with those reported in the literature. In these alternative scenarios, the least-cost workforce sustained would vary by 150 to 200 people—higher in the pessimistic scenario and lower in the optimistic one. Costs, of course, follow. At EB, costs in the optimistic scenario would be about 5 percent below those for the 15-year design baseline, and in the pessimistic scenario, over 20 percent higher.

It is important to recognize that the less costly alternatives—sustaining a workforce in excess of demand or, preferably, extending the design period to 20 years—have nontrivial drawbacks that are not easily quantified. Sustaining a workforce in excess of demand raises the question of what the excess workers are to do to maintain their skills. There are several options available that address aspects of the problem, but even if combined and coordinated with other activities, these options may not keep skilled personnel from leaving or sustain the skills of those who stay as effectively as design work on a new submarine class would. Extending the design period to 20 years raises various risks, such as increased overhead and design obsolescence by the time the first submarine of the class takes to sea. Of course, "doing nothing" risks the loss of key submarine skills.

Critical Skills

We have established the need to sustain 800 designers and engineers at EB, or 1,050 at NGNN, through the design gap if costs are to be minimized. These numbers should include representatives from all the various skill groups, to ensure that all skills will survive a gap and that there will be an adequate base of mentors able to reconstitute those skills in the workforce. The specific number to be sustained from each skill group will depend on various factors relating to the future demand for each skill, the probability of losing each skill, and the difficulty of reconstituting it. Those factors include

- The technical specifications of the next submarine design. If there is expected to be a significant change from the current design, the distribution of skills to retain should reflect that. For example, if it is likely that the next design will use electric drive, more electrical and fewer mechanical engineers will be required.
- Workforce demographics. Skill groups with older workforces need more management attention to ensure that a critical mass is not lost. About half the planning and production workforce at NGNN and most of the engineering support workforce at EB are over 50.
- Ability to find skills outside the nuclear submarine industry. Certain skills may be exercised in nuclear submarine design only, e.g., acoustics engineers and signals analysts who specialize in silencing and structural engineers specializing in shock. If these skills are lost, reconstituting them will be more challenging than for other types of skills.
- Time to gain proficiency. Skills that take a particularly long time to develop (because they require either a great deal of formal education or occupational training time) are also more challenging to reconstitute than skills that take less time to develop. Approximately 10 percent of technical skills, for example, require 10 years of on-the-job experience to develop.
- Other supply and demand factors. These may affect the availability of certain skills or the ease with which individuals with particular skills can be attracted to industry. The number of nuclear engineering programs in U.S. universities, for example, has fallen by about half over the past 30 years. Partly as a result, the supply of workers is decreasing in certain key areas. At the same time,

the U.S. Department of Energy forecasts that new nuclear power plants will be needed by 2025, which suggests a competing demand for nuclear engineers.

Suppliers

Submarines, like other large, complex systems, are not designed by a single firm. A single firm cannot productively sustain all the special skills required. The submarine design base thus includes a large number of subcontractors that contribute design expertise or engineered components to plug into the system. How will these firms be affected by a gap in design demand?

To find out, we surveyed 58 suppliers identified by the shipbuilders as having significant activities associated with submarine design. We received responses from 38 of the 58 firms the shipbuilders identified; 32 felt that they had significant activities associated with submarine design. We analyzed these 32 responses according to a set of indicators of potential risk in the design industrial base:

- Percentage of revenue generated by design work. Only one firm got most of its revenue from design. Considered alone, this suggests that most firms could weather a design gap.
- Percentage of revenue from submarine business. Three-quarters of the firms got less than half their revenue from the submarine business—another indicator that a design gap would not have a large impact.
- Absence of competitors. Only five firms believed they had no competitors, suggesting that in the event some suppliers fail, the shipbuilder will typically have alternatives.
- Insufficient design workforce supply. Most suppliers indicated they would not have a problem maintaining a technical workforce within the next 10 years—a period that extends through the expected SSBN design start date. About half foresee trouble beyond that, though.
- Percentage of workforce in upper age range. At over half the firms, most of the workforce is more than 45 years old. This is problematic because it suggests that many workers could approach retire-

ment over the course of a submarine design gap. Not only will such workers be unavailable to meet workforce demand, they will not be there to mentor younger workers.
- Time required to ramp up a design staff. Two-thirds of the firms thought that it would take a year or less to ramp up for a new submarine design effort. There appears to be little problem in that regard.
- Time required before a new hire is productive. Most respondents judged that it would take over six months for new hires to become adapted to the firm and proficient in their role.
- Extent to which employment falls short of demand peak for design. The great majority of firms indicated that they already had sufficient staff to meet the peak design demand from a new submarine program.

The survey results suggest some reason for concern. In their comments to us, suppliers were generally concerned over the lack of demand for submarine design in the near term. Furthermore, while we cite various favorable majorities, for all the indicators some firms show a degree of risk. Eight firms exhibited risk in more than one category.

There are several possible options available for addressing supplier risk. One is to stretch the submarine design (e.g., to 20 years) to provide some near-term work and cut down the variability of demand. Spiral development of the *Virginia* class could also provide work for some suppliers. Other risk reduction measures would seek to compensate for the loss of a supplier. For some inputs, an alternative supplier could be sought. For others, the technology the vendor supplies might be replaced by some newer (or older) technology or the current design might be retained.

Most of these options are not applicable to all suppliers, as the situations of the different firms vary. In particular, stretching the design duration, a promising option for addressing the design gap at the shipyard, will not work for most of the vendors. The choice of intervention, or mix of interventions, will have to be tailored to each vendor at risk.

Navy Roles and Responsibilities

The Navy is ultimately responsible for a safe, effective, and affordable submarine design. In carrying out this responsibility, the Navy fulfills three roles: It provides technical infrastructure and expertise, it designs and develops certain critical components, and it supports submarine-related science and technology.

In providing technical infrastructure and expertise, the Navy plays the role of smart buyer. That is, it must ensure that the design efficiently meets Navy program requirements. In this capacity, for example, the Navy implemented integrated process and product development in the design of the *Virginia* class, an innovation intended to save time and money by making Navy design reviews a part of the ongoing effort rather than a milestone occurrence. Another aspect of the infrastructure and expertise provided by the Navy is its role as the technical authority. This role is taken on specifically by an array of technical warrant holders, each of whom certifies within his or her area of expertise that the design is safe, technically feasible, and affordable. Finally, the Navy is responsible for design-phase testing and evaluation.

The Navy retains sole responsibility for designing and developing components that are associated with the nuclear propulsion plant, critical to submarine safety, critical to the integration and interoperability of the command-and-communication and combat-control systems, or not commercially viable for private industry to design. Submarine-related science and technology is integrated through the Submarine Technology (SUBTECH) program, which consists of integrated product teams focusing on communications, weapon systems, self-defense, and hull and propulsion issues.

One of the strengths of the Navy's acquisition process is the separation of the responsibility for managing acquisition programs from the technical approval process. Program managers are responsible for program performance in cost and schedule terms. The Navy's technical establishment is responsible for the technical acceptability of the product design. In this way, safety issues are not subject to trade-offs against costs or schedule concerns.

The Navy's design resources are physically and organizationally dispersed between the headquarters of the Naval Sea Systems Command (NAVSEA) and its naval warfare centers. NAVSEA engineers oversee the design, construction, and support of the Navy's fleet of ships, submarines, and combat systems. The naval warfare centers are charged with carrying out many of the specific activities supporting the Navy's design responsibilities, described above. The Naval Surface Warfare Center (NSWC) is responsible for hull, mechanical, and electrical (HM&E) systems and propulsors for both surface and undersea vessels. The Naval Undersea Warfare Center (NUWC) is responsible for submarine weapons and combat systems.

The current division of responsibilities between NAVSEA and the warfare centers reflects a transition from a state in which more people were housed within NAVSEA. A major purpose of that transition was to move staffing from mission-funded positions, billable to Navy overhead, to program-funded positions, billable to a PEO. The warfare centers operate more like private contractors, billing their time to specific accounts and moving personnel to wherever the work is needed. This has obvious implications for the conservation of submarine design expertise in the Navy.

Impact of a Design Gap on the Navy

As with the shipyards, a design gap could affect the Navy through personnel termination, consequent skill loss, impediments to the development of managers, and eventual hiring and training, or rehiring and retraining, with all the costs those involve. There is also the possibility that some skills, once lost, could be difficult to regain.

The effects of a gap would vary by organization. As a mission-funded organization, NAVSEA's technical infrastructure would likely survive a submarine design gap. However, the ability to perform certain technical oversight functions could degrade without the opportunity to exercise those functions. Whole-ship integration skills could be particularly affected. The lack of relevant work could also retard the development of proficient senior managers in the submarine design area.

The impact of a design gap on the naval warfare centers depends on the technical areas involved. Non-HM&E areas are relatively insensitive to the gap, because this work is performed at NUWC, where in-service modernization programs make up the bulk of program funding and provide a healthy technical basis for new submarine design. However, at NSWC's Carderock Division, ongoing in-service submarine support, technical assistance to the *Virginia*-class production program, and science and technology programs will not support the skills required for a full submarine design effort. As a result, engineers and designers who have been working on the *Virginia* design will shift to funded programs (i.e., those unrelated to submarines) or leave. Keeping some of these people working on tasks more relevant to submarine design—that is, maintaining a core submarine design group of personnel and facilities—would require an additional \$30 million to \$35 million per year of funding for Carderock during the design gap.

Here, as in the case of the shipyards, stretching the design duration from 15 to 20 years would allow an early start and avoidance of the design gap. Costs and proficiency losses would thus be avoided.

Recommendations

From the preceding analysis, we reach the following recommendations:

- Seriously consider starting the design of the next submarine class by 2009, to run 20 years, taking into account the substantial advantages and disadvantages involved.

If the 20-year-design alternative survives further evaluation, the issue of a gap in submarine design is resolved, and no further actions need be taken. If that alternative is judged too risky, we recommend the following:

- Thoroughly and critically evaluate the degree to which options such as the spiral development of the *Virginia* class or design without construction will be able to substitute for new-submarine design in allowing design professionals to retain their skills.

If options to sustain design personnel in excess of demand are judged on balance to offer clear advantages over letting the workforce erode, then the Navy should take the following actions:

- Request sufficient funding to sustain excess design workforces at the shipyards large enough to permit substantial savings in time and money later.
- Taking into account trends affecting the evolution of critical skills, continue efforts to determine which shipyard skills need action to preserve them within the sustained design core.
- Conduct a comprehensive analysis of vendors to the shipyards to determine which require intervention to preserve critical skills.
- Invest $30 million to $35 million annually in the NSWC's Carderock Division submarine design workforce in excess of reimbursable demand to sustain skills that might otherwise be lost.