The U.S. Navy Submarine Fleet: Construction and Maintenance Issues

John Voyer, Ph.D.
Professor Emeritus of Business Administration
University of Southern Maine

voyer@maine.edu

+01 207-274-3261

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Abstract

The United States Navy's fleet of attack submarines, ballistic missile submarines, and guided missile submarines is smaller than its policymakers want it to be. Its industrial base of submarine manufacturers and maintenance infrastructure and workers is also depleted. A system dynamics model that replicated the construction and overhaul structure of the fleet and its industrial base tested several scenarios. The tests revealed the following recommended policies: Continuing the current production policy that leads to three attack subs manufactured per year by 2050; ensuring an overhaul time of no longer than one year for attack subs and an overhaul time of sixteen months for the new ballistic missile submarines; maintaining the current realistic worker attrition rates of no more than ten percent; doing hiring pulses of 10,000 for construction and 4,200 for overhaul workers each year over the next twenty-five years; and doing better workforce training.

United States Navy Submarine Fleet: History, Submarine Types, and Current Fleet Size

The United States Navy has had a fleet of submarines since 1901, when it commissioned its first. The fleet quickly grew to ninety-one in 1919, just after the end of World War I. The fleet shrank to forty-nine by 1936, but swelled to 232 by the end of World War II in 1945. Through 1951, all U.S. Navy submarines were attack submarines (Naval History and Heritage Command, 2025). According to the U.S. Naval Academy, attack submarines "are capable of performing seek-and-destroy missions on enemy ships and subs, surveillance and reconnaissance, irregular warfare, covert troop insertion, mine and anti-mine operations…."; existing attack submarines also carry a limited number of cruise missiles (United States Naval Academy, 2026). During the Cold War, the attack submarine fleet grew to a peak of 113 in 1957; by 1989, the fleet had gradually diminished to ninety-nine vessels. In 2025, the Navy had fifty-three attack submarines (Naval History and Heritage Command, 2025).

Starting in 1951, the U.S. Navy began adding a new kind of submarine, ballistic missile, to its fleet. Ballistic missile submarines are the sea-based leg of the so-called "Nuclear Triad" of deterrence (the other two legs being land-based Inter Continental Ballistic Missiles [ICMBs] and air-based heavy bombers). According to a Government Accountability Office report, ballistic missile submarines "… are designed to maximize stealth to remain undetected while on patrol at sea. This survivability gives the United States a credible ability to retaliate if faced with an attack targeting other legs of the triad, and explains DOD's decision to ultimately deploy up to 70 percent of the nation's nuclear warheads on SSBNs [ballistic missile submarines]" (United States Government Accountability Office, 2017). By 1967, the Navy's ballistic missile submarine fleet had reached forty-one vessels, a size it maintained until 1979. Since 2004, this fleet has had a constant size of fourteen vessels (Naval History and Heritage Command, 2025) because "the 1994 Nuclear Posture Review determined that the United States needed only 14 of its 18 SSBNs to meet the nation's strategic force needs. Therefore, the Navy decided to transform four Ohio-Class [ballistic missile] submarines into conventional land attack and [Special Operation Forces] platforms" (America's Navy, 2023b).

Consequently, starting in 2003, the Navy added a third type of submarine, the guided missile submarine. As mentioned in the preceding paragraph, these were ballistic missile submarines converted in two ways: a larger armory of cruise missiles (about four times as many as an attack submarine) and "lockout chambers" (a type of airlock, used only underwater) to release and recover Special Operation Forces personnel while submerged (America's Navy, 2023a). The Navy currently maintains a fleet of four guided missile submarines (Naval History and Heritage Command, 2025).

In 2025, the U.S. Navy's submarine fleet numbered 71 vessels: 53 attack submarines, 14 ballistic missile submarines, and 4 guided missile submarines. All seventy-one vessels are nuclear powered (Nuclear Threat Initiative, 2024). The Navy's first nuclear submarine, the USS Nautilus, joined the fleet in 1954 (Naval History and Heritage Command, 2026). Since 1959, only nuclear-powered submarines have been built, and since 1990 the entire fleet has been exclusively nuclear powered (Suciu, 2023).

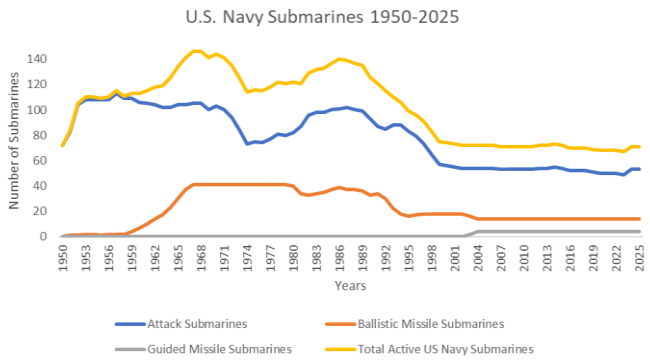

Figure 1. The U.S. Navy Submarine Fleet, 1950-2025

As Figure 1 shows, over the last 75 years the U.S. Navy submarine fleet changed as perceived strategic national security threats changed. Fleet size responded to what policymakers determined was needed to meet those threats. The figure shows that, during the Cold War (approximately 1950 to 1990), policymakers wanted high numbers of attack and ballistic missile submarines. After 1990 (the approximate end of the Cold War), submarine numbers began dropping and leveling out, as shown in the blue (attack submarines) and orange (ballistic missile submarines) lines of Figure 1. Figure 1 also shows that, in 2004, the Navy converted four of its eighteen ballistic missile submarines (orange line) into guided missile submarines (gray line).

Submarine Construction Issues

In the United States, two private companies perform all submarine construction: General Dynamics's Electric Boat (Groton, Connecticut) and Huntington Ingalls Industries' Newport News Shipbuilding (Newport News, Virginia) (Weisgerber, 2026). The U.S. Navy has a goal of producing two attack submarines and one ballistic missile submarine per year by 2028, with sustained production at that level for the foreseeable future (Taylor, 2025). However, many observers have noted that the two shipyards have lagged far behind that level of production. The newest ballistic missile submarine was, as of late 2025, twelve to eighteen months behind schedule (Taylor, 2025). The Department of the Navy announced in 2024 that it would procure one attack submarine in its 2025 budget, half the number of the objective (Hendrix, 2024). Submarine production pressure is exacerbated by the AUKUS agreement, in which the United States has agreed to sell three nuclear powered attack submarines to the Australian navy sometime in the 2030s while Australia develops its own attack submarines, with the possibility of selling a maximum of two more if Australian submarine development lags (Australian Submarine Agency, 2024).

Observers point to a depleted “industrial base” as the major impediment to building more submarines in a timely way. This depletion is a combination of constrained capacity at Electric Boat and Newport News Shipbuilding shipyards and, perhaps more importantly, a reduction in the number and experience level of the workforce (Hendrix, 2024; United States Government Accountability Office, 2025). Hendrix (2024) points out that the workforce issue began in the early 1990s, when the government reduced submarine construction capacity as part of the federal government’s effort to get a “peace dividend” from purportedly reduced global tensions. The average level of experience prior to the COVID pandemic was just under fifteen years, but post-COVID it has dropped to somewhere between five and seven years, mostly because many longtime workers retired during the pandemic (Hendrix, 2024). While the traditional submarine construction workforce had worked under what Hendrix calls “robust pensions,” the more recent workforce works with portable 401(k) retirement plans; between the difficulty of the work, the time-consuming need to certify workers, and the portable retirement plans, retention has become a new and difficult contributor to the reduced and less experienced workforce (Hendrix, 2024).

Submarine Maintenance Issues

Because of the structural and mechanical stress of operating at sea, and to ensure that they achieve their design life, submarines need repairs approximately every four to six years (United States Government Accountability Office, 2020). There are four types of repair and overhaul processes (Chief of Naval Operations, 2022):

- **Organizational Level Maintenance (OLM)**. These are repairs performed by a submarine's crew between formal overhauls, e.g., inspecting, servicing, lubricating, and replacing minor parts or subassemblies.
- **Depot Modernization Period (DMP)**. The Navy does these modernization and repair periods approximately every six years. They typically involve inspecting and repairing the vessel’s hull, upgrading sonar, navigation, communications, and weapons systems, overhauling mechanical and electrical systems, testing crew safety systems, and training and re-qualifying the crew. The goal for DMPs is to accomplish them in no more than one year.
- **Engineered Overhauls (EOH)**. These typically occur at the midpoint of a submarine’s design life. These involve major structural repairs, system modernization, mechanical and propulsion overhaul, safety certifications, habitability upgrades (if needed on older boats to accommodate female sailors), and sea trials and certification. The goal is to accomplish the EOH in two to three years.
- **Refueling and Overhaul (ROH)**. These also occur during a submarine’s midpoint of design life, but mostly for older submarines. (Newer submarines have “life of ship”

nuclear reactors, so they do not need the refueling.) Nuclear refueling on an older submarine involves cutting the ship open to gain access to the nuclear reactor. While the ship is open, workers upgrade or overhaul weapons and mechanical systems, test the vessel's structural integrity, and upgrade its habitability. Once workers reassemble the ship, they restart the power plant and do sea trials. The EOH process takes three to four years.

For various reasons, the Navy has missed most of its repair time goals in recent years (Hendrix, 2024; Taylor, 2025). To begin with, submarine repair and overhaul occur at four public shipyards (Naval Sea Systems Command, 2026):

- Norfolk Naval Shipyard (Norfolk, Virginia)
- Portsmouth Naval Shipyard (Kittery, Maine)
- Puget Sound Naval Shipyard and Intermediate Maintenance Facility (Bremerton, Washington)
- Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility (Pearl Harbor, Hawaii)

These shipyards have insufficient physical capacity (ten drydocks when at least fifteen are needed to meet maintenance time goals) and worker capacity needed to achieve the repair and overhaul time goals listed earlier (Buckby, 2026; Hendrix, 2024; Latham, 2025). The four public shipyards employ a total of 43,500 workers, although three of the yards (Norfolk, Puget Sound, and Pearl Harbor) dedicate roughly half their workers to ships other than submarines, such as aircraft carriers and surface combatants; consequently, their workforce dedicated to submarine repair is roughly 25,000.

An example of delayed repair is the USS Connecticut attack submarine, which hit a seamount in 2021 while submerged in the South China Sea; its repairs will not be completed until at least September, 2026 (Wicker, 2023). An even more egregious example is the USS Boise attack submarine, which one observer called the "poster child" for the Navy's maintenance backlog (Panella, 2025). The Navy scheduled it for an overhaul in 2015, and it lost its dive certification in 2017 while waiting for a drydock space. It did not get into drydock until 2021, but waited until 2024 for funding for the overhaul. As of early 2026, it was still under repair, and it is scheduled to return to sea in 2029, *fourteen years* after its designation for overhaul (MacDonald, 2025).

An obvious side effect of these maintenance and overhaul delays is that the Navy's fleet of *active* submarines is significantly lower than the *overall size* of its submarine fleet. Latham (2025) estimates that in recent years the active submarine fleet has dropped to as little as sixty percent of its overall fleet size; Wicker (2023) provides a similar estimate. This obviously creates a national security threat (Buckby, 2026; Hendrix, 2024; Latham, 2025; MacDonald, 2025).

Dynamic Hypothesis

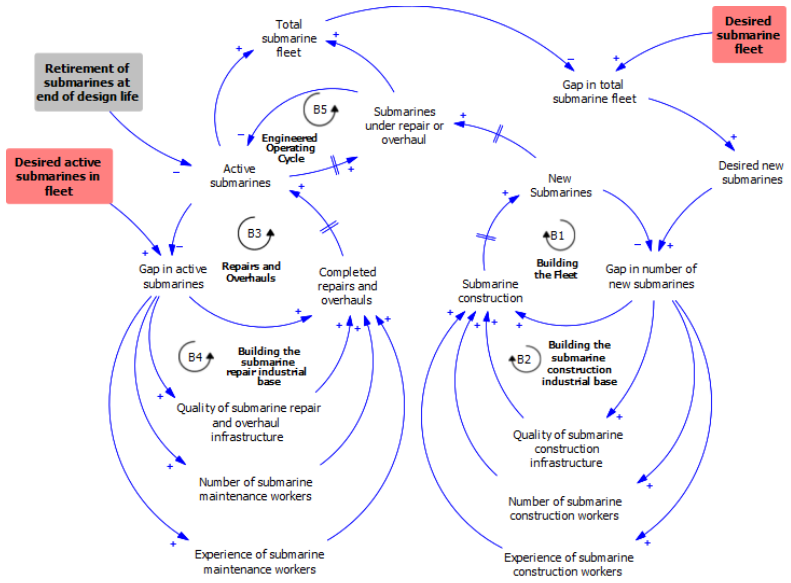

Figure 2. A Dynamic Hypothesis of the U.S. Navy's Submarine Fleet and Industrial Base

Figure 2 shows a dynamic hypothesis of the United States Navy submarine fleet and its industrial base. Please note: the structure of this dynamic hypothesis holds for each of the three types—attack, ballistic missile, and guided missile—submarine. The variable shaded in gray in Figure 2 captures how submarines have a limited "design life." This varies by type of submarine, but all submarines have a finite lifespan. The rigors of operating at sea will eventually wear out even the best-designed and best-maintained submarine.

The variables in red shading in Figure 2 show the two key policy choices made by the Navy's civilian and military policymakers:

- The desired overall size of the submarine fleet.
- The desired number of *active* submarines in the fleet.

Since 1950, which is the scope of the present paper, these two policy decisions, particularly the first one, have driven the overall size of the fleet and its number of active submarines.

The dynamic hypothesis contains five balancing loops:

- Loop B1, "Building the Fleet." A gap between current fleet size and desired fleet size triggers construction of new submarines. Note the delay marker on the link between Submarine Construction and New Submarines.
- Loop B2, "Building the Submarine Construction Industrial Base." The need for new submarines triggers improvement or enlargement of the three elements of the industrial base: shipyard infrastructure, number of workers, and experience level of workers.
- Loop B3, "Repairs and Overhauls." On a specified schedule, or as the result of accidents, serious breakdowns or other mishaps, submarines must undergo repairs or overhauls of various intensities, as described earlier. This reduces the number of deployed active

submarines. When shipyards complete repairs and overhauls, submarines return to active duty, until their next scheduled maintenance.

- Loop B4, “Building the submarine repair industrial base.” As in the case for construction of new submarines, the need for submarine maintenance triggers improvement or enlargement of the three elements of the repair industrial base: shipyard infrastructure, number of workers, and experience level of workers.
- Loop B5, “Engineered Operating Cycle.” Just as new submarines have scheduled maintenance, so do older ones, so long as they have not reached their design life. Once refurbished, these older submarines return to being active—until their next scheduled maintenance, or the end of their design life. The official Navy term for submarines’ cycling between being active and undergoing maintenance is “Engineered Operating Cycle” (Chief of Naval Operations, 2022).

Richardson (1986) pointed out that balancing loops may certainly lead to growth, specifically as a system "seeks" a goal that is higher than its current state. However, sometimes the goal of a balancing loop is *lower* than its current state. Both growth and decline are possibilities for Loops B1 through B4 in this dynamic hypothesis, as the Navy’s history of fluctuating fleet size requirements illustrates. However, Loop B5 merely cycles submarines between active and sidelined status, exhibiting no growth, or decline, on its own.

Stock and Flow Model of Dynamic Hypothesis

The next two pages show the three views of a stock and flow model formulated to capture the dynamic hypothesis. Figure 3 shows the “Construction and Overhaul View.” Its three panels show the systemic structure for construction and overhaul of each type of submarine: Attack Submarine (Panel A); Ballistic Missile Submarine (Panel B); and Guided Missile Submarine (Panel C). These structures are subtly different, but overall act as follows:

1. Policymakers decide to increase or decrease the size of the fleet for a type of submarine.
2. Construction increases the stock of a type of active submarine. Retirement reduces the stock of a type of active submarine.
3. Sending a type of submarine to overhaul or maintenance also reduces its stock of active submarines. Completing the overhaul or maintenance increases that stock of active submarine.
4. Construction and overhaul of submarines are affected by the size and quality (in terms of experience) of their respective workforces (we show those structures in Figure 4).

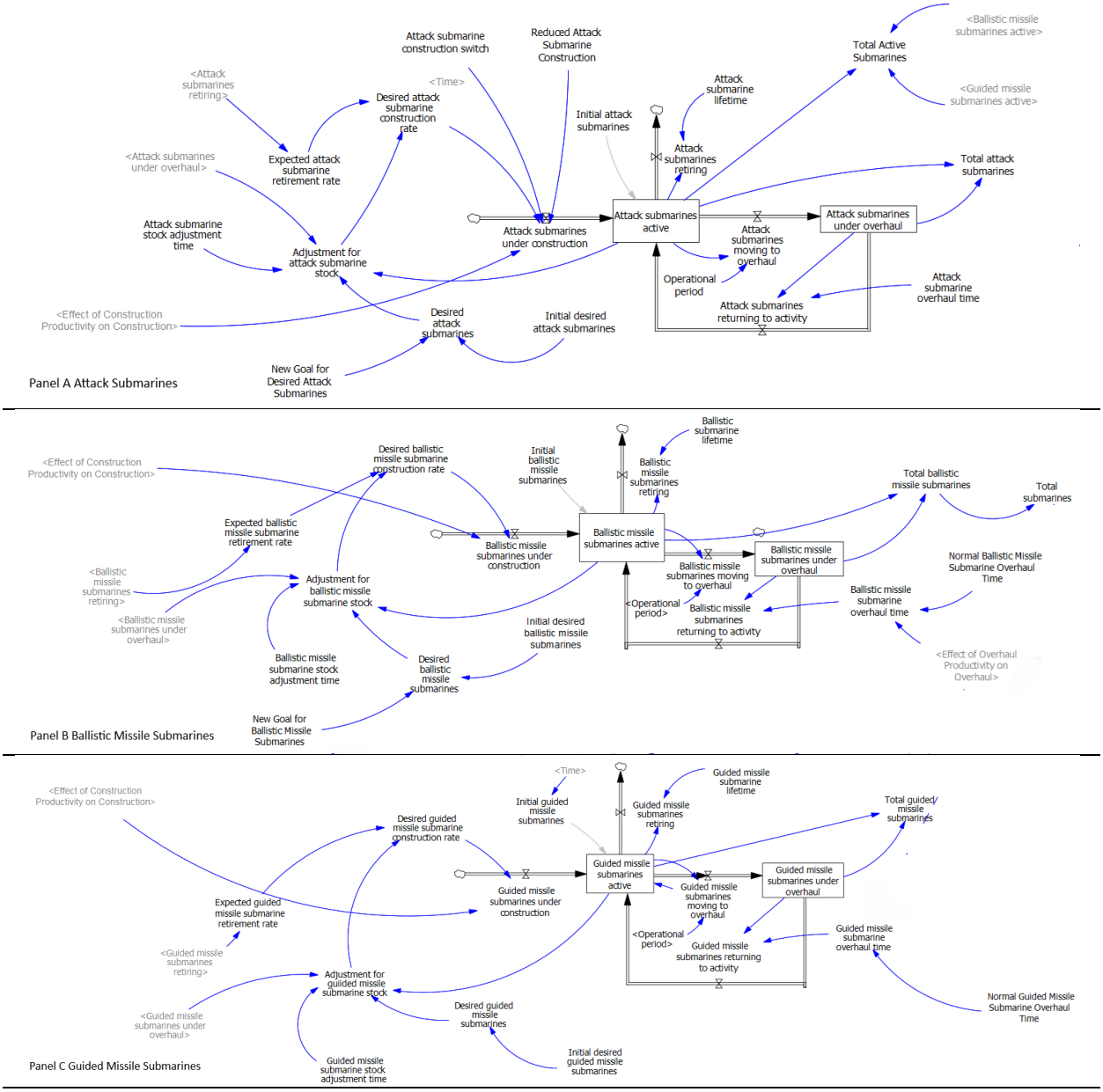

Figure 3. Stock and Flow View of U.S. Navy Submarine Fleet Construction and Maintenance, by Type of Submarine

Figure 4 shows the structures for the construction (Panel A) and Overhaul (Panel B) views of the stock and flow model. The structures are similar, but vary subtly in numbers. Changes in the desired number of submarines trigger hiring (for increases) or increased attrition (for decreases). In a co-flow structure, changes in hiring and attrition produce changes in the average experience of the workforce.

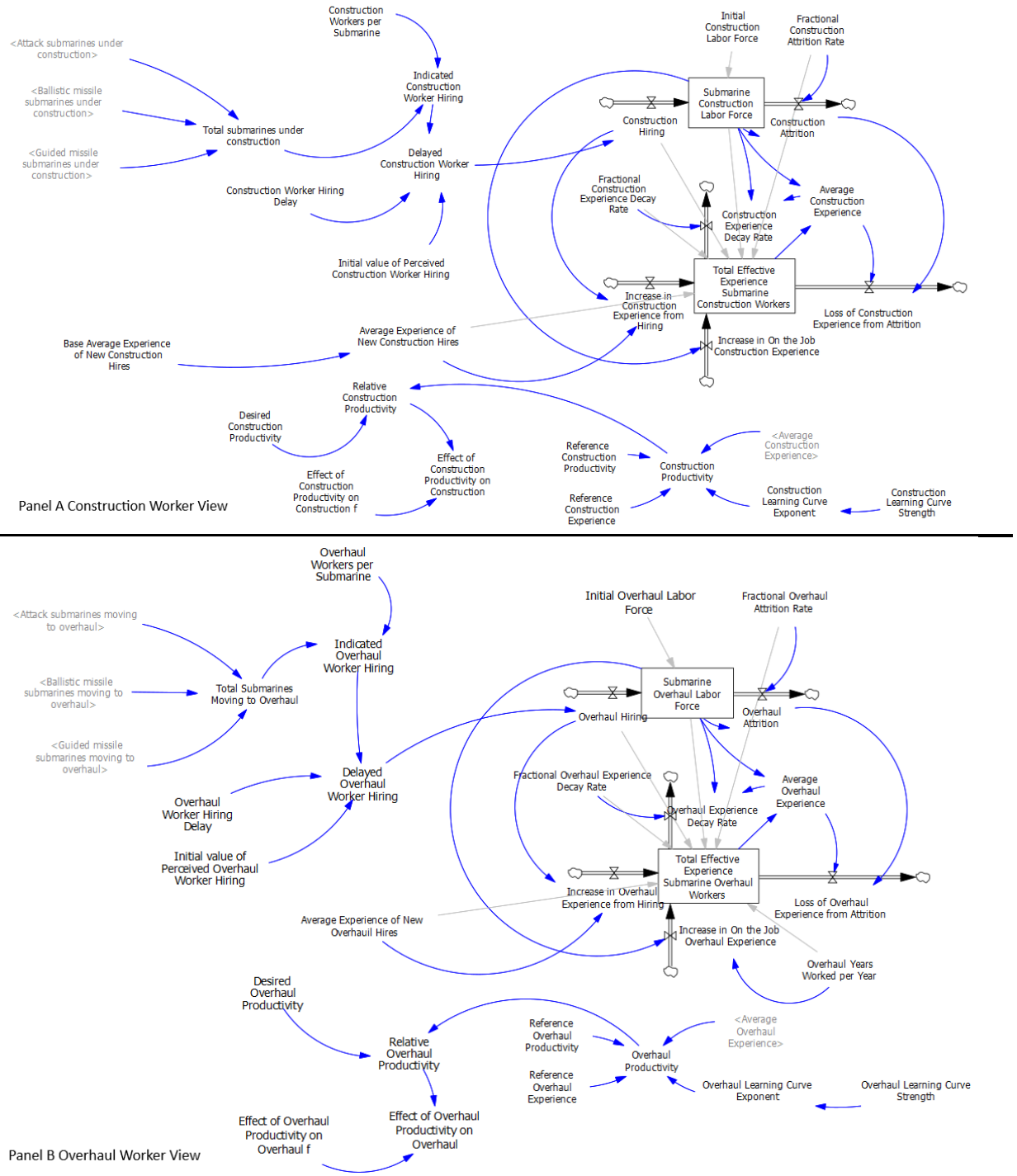

Figure 4. Stock and Flow View of Construction and Maintenance of U.S. Navy Submarine Fleet

Era	Estimated Direct Construction Workforce (Major Yards)
1980s (Peak)	~48,000 workers
1990s (Low)	~12,000 - 17,000 workers
2024-2025	~40,000+ workers (combined NNS & EB submarine-related staff)

Table 1. Estimated Submarine Construction Workforce, 1980-2025. (Source: Hendrix, 2024)

Comparison of Model to Data: Submarines

Although it was a bit tedious to format, data on the number of submarines were relatively easy to get (Naval History and Heritage Command, 2026). Figure 1 (shown earlier) shows the fleet levels for each of the three kinds of submarines from 1950 to 2025.

More difficult were data on the number of employees at the two construction and four maintenance shipyards. Table 1 shows the estimated number of manufacturing workers in the two major submarine shipyards.

Period	Total Public Shipyard Workforce (Approx.)	Key Submarine Maintenance Context
Early 1950s	~40,000 - 60,000+	High surge for Korean War; transition to nuclear power.
Late 1980s	~70,000+	Supported peak fleet of 98 attack submarines.
Late 1990s	~20,000 - 25,000	Consolidation after multiple shipyard closures.
2024–2025	~37,000 - 39,000	Current push to eliminate massive maintenance backlogs.

Table 2. Estimated Submarine Maintenance Workforce Summary (Source: Hendrix, 2024)

Data on employment in submarine repair and overhaul is similarly hard to obtain. Table 2 shows a summary of those data. For both manufacturing and maintenance, the author constructed a spreadsheet of estimated employment levels that were consistent with the estimates in Tables 1 and 2.

Figure 5 on the next page has four panels showing how the model's output compared to the data for the three types of submarines and for the overall number of submarines. Panel A shows the comparison for attack submarines; Panel B shows the comparison for ballistic missile submarines; Panel C shows the comparison for guided missile submarines; and Panel D shows how the model's output compares to data for the total number of submarines. The comparisons between model output and historical data are not perfect, but they are plausibly close.

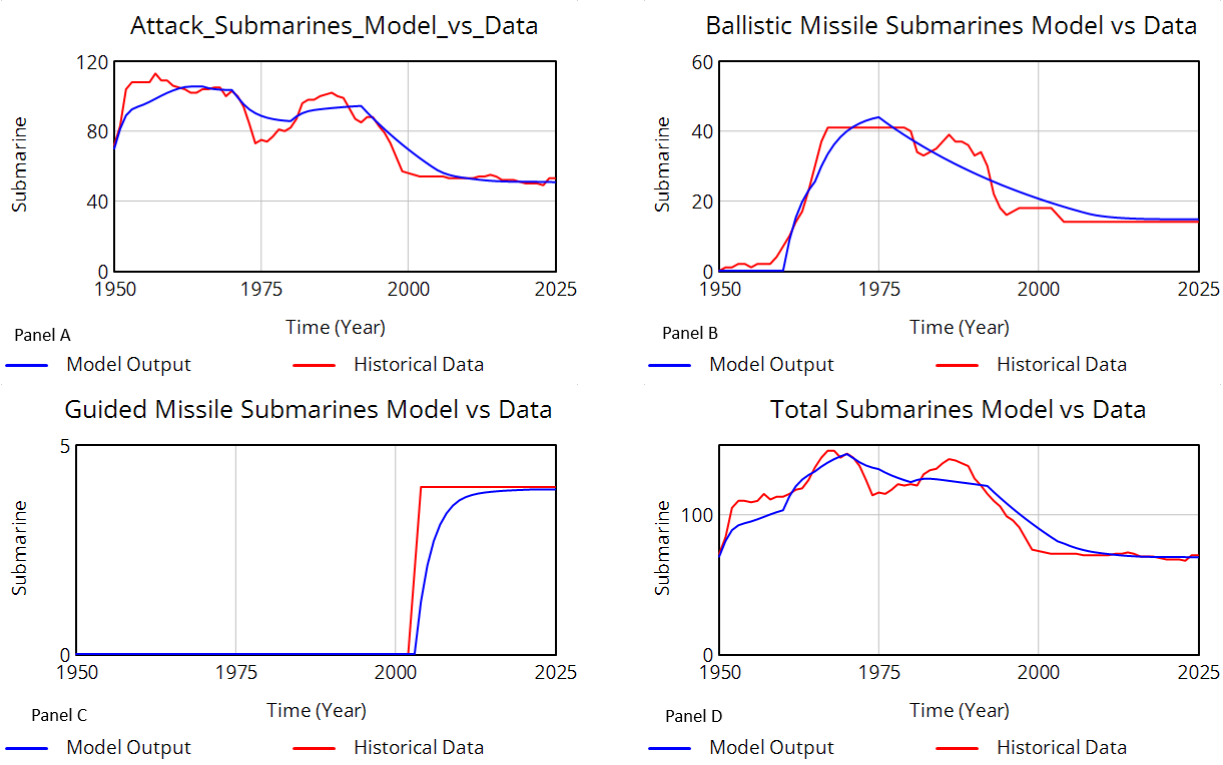

Figure 5. Submarines, Model vs. Data, 1950-2025

Comparison of Model to Data: Construction and Overhaul Workforces

Figure 6 has two panels showing how the model's output compared to the data for the two types of workforces—construction and overhaul. Panel A shows the comparison for the construction workforce, while Panel B shows the comparison the overhaul and repair workforce. Again, the comparisons between model output and historical data are not perfect, but they are plausibly close.

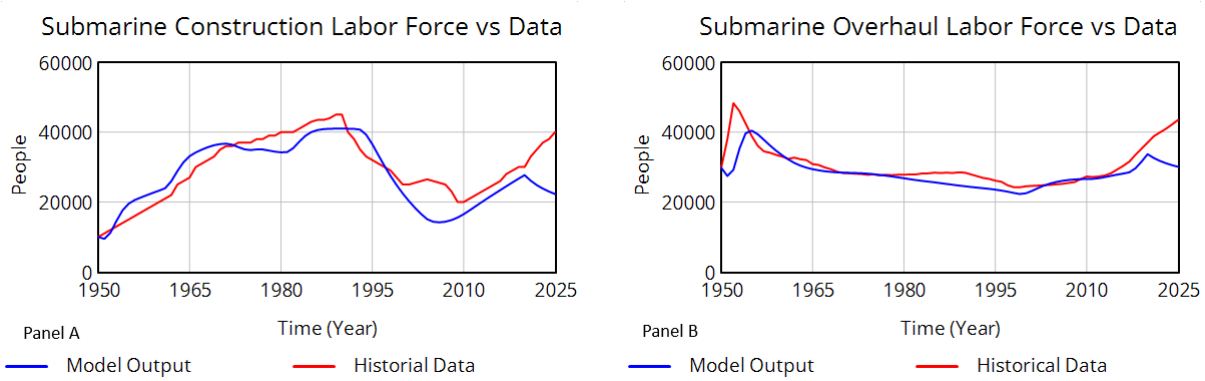

Figure 6. Workforces, Model vs. Data, 1950-2025

Figure 7 shows what the base model generates for years 2025 to 2050. Because of treaty-based limits on ballistic missile submarines, and because of the debut of a more sophisticated and

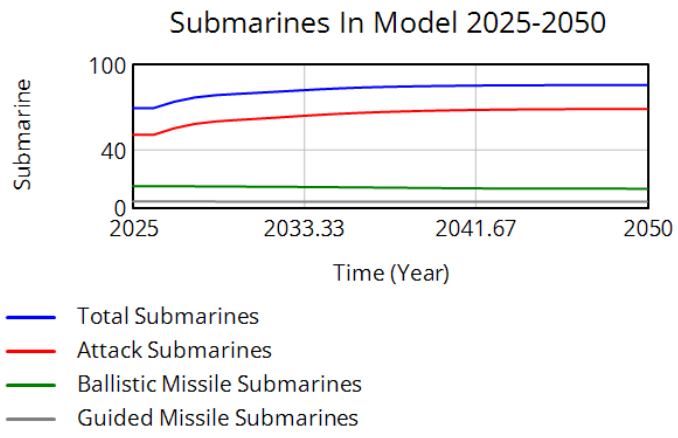

Figure 7. Submarine Levels in Model, 2025-2050

durable type of ballistic missile submarine (the "Columbia-class"), those drop from fourteen to twelve. The number of guided missile submarines does not change from its current four. Attack submarines rise from approximately fifty-one to approximately sixty-nine. These totals mirror fairly well the Navy's desired number of submarines for that period—sixty-six attack submarines, twelve ballistic missile Columbia-class submarines, and four guided missile submarines (Latham, 2025).

Experiments Related to Issues with the U.S. Navy Submarine Fleet

Continuing to Produce One Attack Submarine per Year

Recently, the Department of the Navy has announced that it wishes to ramp up production to at least two attack submarines per year by 2028 (Heckman, 2025). This paper's model incorporates that policy goal, and its base case shows that, between 2026 and 2050, production could reach three attack submarines per year, which would help with the U.S. Navy's goal and also reduce the pressure created by the AUKUS agreement (Australian Submarine Agency, 2024). However, the author tested a scenario where this policy was *not* achieved, and production remain stalled at one attack submarine per year. Figure 8 shows the result of this scenario test.

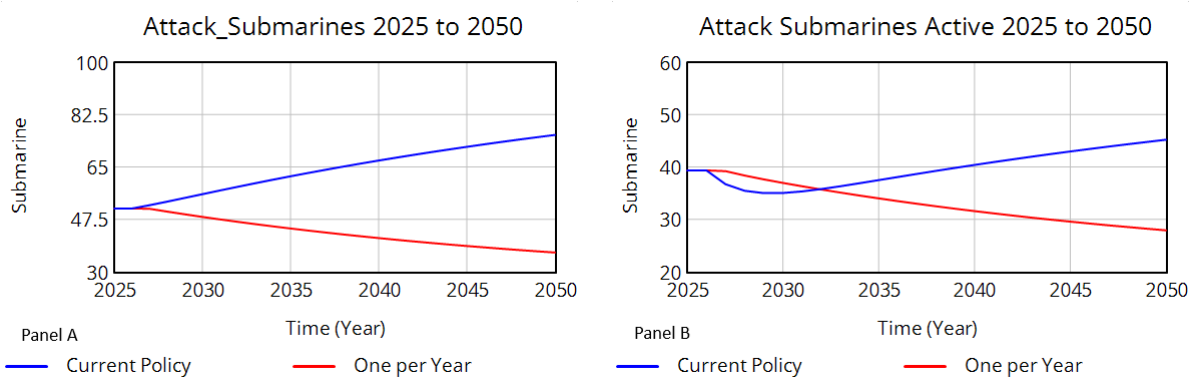

Figure 8. Effects on Attack Submarine Fleet If One Constructed Per Year

Figure 8 shows that this would result in a very serious deficit of attack submarines for the Navy, which has a military requirement of sixty-six boats, with fifty-three active boats at any given time. In this scenario, not only would the total number of attack submarines drop below forty, the number of *active* attack submarines would drop below thirty.

Increase (and Decrease) in Overhaul Time for Attack Submarines

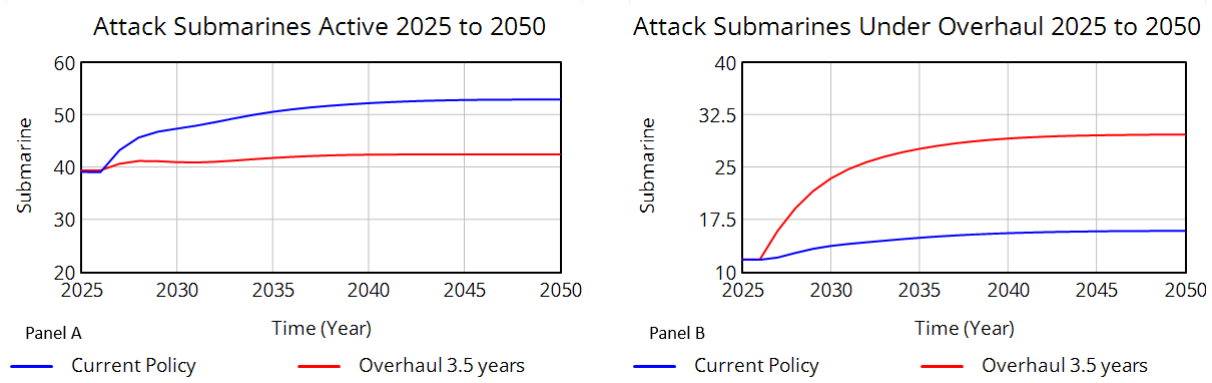

Figure 9. Number of Attack Submarines Active and Under Overhaul with Overhaul Time of 3.5 years

As mentioned earlier, in recent years the U.S. Navy has struggled to get its attack submarines overhauled in a timely fashion. The goal has been one year, but it has been about 1.5 years (or longer) since the early 1980s. Figure 9 shows what would happen if the overhaul time were to increase to 3.5 years (a period well withing the realm of possibility (Hendrix, 2024)). Panel A shows that the number of active attack submarines would dwindle to approximately forty-one, well below the sixty-six (Wicker, 2023) that the Navy thinks would be necessary for mission accomplishment. Panel B shows that the number of attack submarines undergoing overhaul, or waiting to be overhauled, would roughly double.

On the other hand, were the Navy and its contractors able to return to a one-year overhaul period for attack submarines, the effects would be beneficial. As Figure 10's Panel A shows, the number of active attack submarines rises to approximately sixty. Panel B shows that the number of attack submarines tied up in maintenance drops to about twelve.

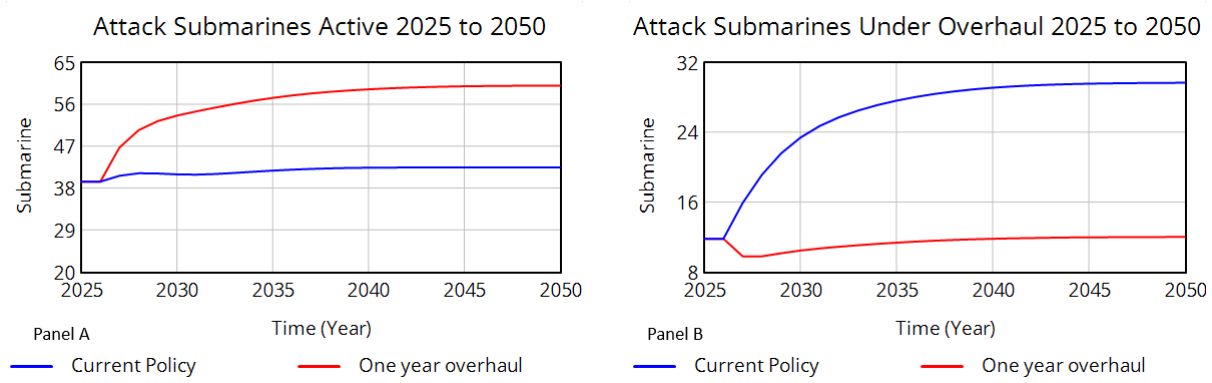

Figure 10. Number of Attack Submarines Active and Under Overhaul with Overhaul Time of 1 year

Longer Overhaul Times for Ballistic Missile Submarines

Our focus so far has been on attack submarines, which make up most of the U.S. Navy's submarine fleet. However, ballistic missile submarines are the important sea-based leg of the

"Nuclear Triad." That fleet currently numbers fourteen Ohio-class submarines, which are close to the end of their designed lifespan. Originally designed for a thirty-year lifespan, they will be forty-two years old by the time their replacements, the Columbia-class submarines, come on line (Balestrieri, 2026; Lagrone, 2022). Boats that old suffer from several maintenance challenges:

- **Structural Integrity**: Hull weakening and metal fatigue increase as these vessels surpass four decades of service.
- **Obsolete Parts**: Because of obsolete materials and designs, many original parts manufacturers are no longer in business. This creates significant hurdles for maintenance teams.
- **Intensive Overhauls**: Extending the life of an older submarine requires a special maintenance period called Pre-Inactivation Restricted Availability (PIRA), an eighteen-month maintenance and modernization period designed to extend the service life of an Ohio-class submarine by three years beyond its current forty-two-year certification.
- **Safety Limits**: Beyond mechanical issues, fundamental limits of the metals in submarines create safety and reliability concerns such that it is unviable to extend service life beyond forty-two years for many hulls. (Balestrieri, 2026)

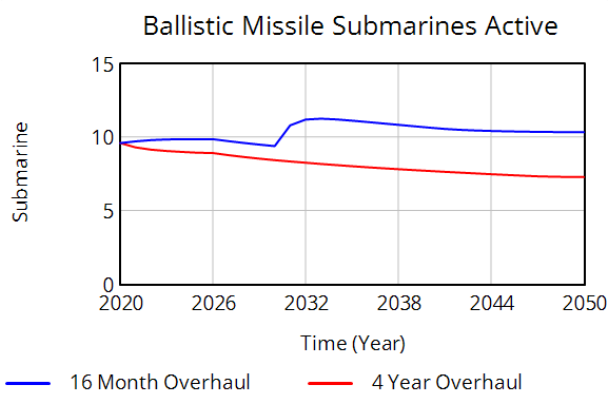

Figure 11. Effects on Number of Active Ballistic Missile Submarines Using 16-month and 4-year Overhaul Periods

Figure 11 contrasts the effects on active ballistic missile submarines of the normal four-year overhaul period compared with the hoped-for sixteen-month overhaul period for the new Columbia-class ballistic missile submarines. It clearly shows that, to maintain a fleet of at least ten boats at sea, hitting the sixteen-month overhaul target is essential. Were the Navy to persist with a four-year maintenance period, the number of boats at sea would be well below what is need to maintain the sea-based leg of the Nuclear Triad. (It should be mentioned in passing that the four guided missile submarines have very short maintenance periods and having three of them deployed at sea has not been difficult.)

Increased Attrition from Construction Labor Force

Historically, the labor force manufacturing submarines was quite stable. Just before the pandemic, the average experience level was just under fifteen years; however, during COVID, "a disproportionate percentage of this workforce retired, dropping the average experience level

down to the five-to-seven-year level … almost overnight" (Hendrix, 2024). Current estimates of attrition level are about twenty percent overall, but first-year recruits having closer to fifty percent (Luckenbaugh, 2025).

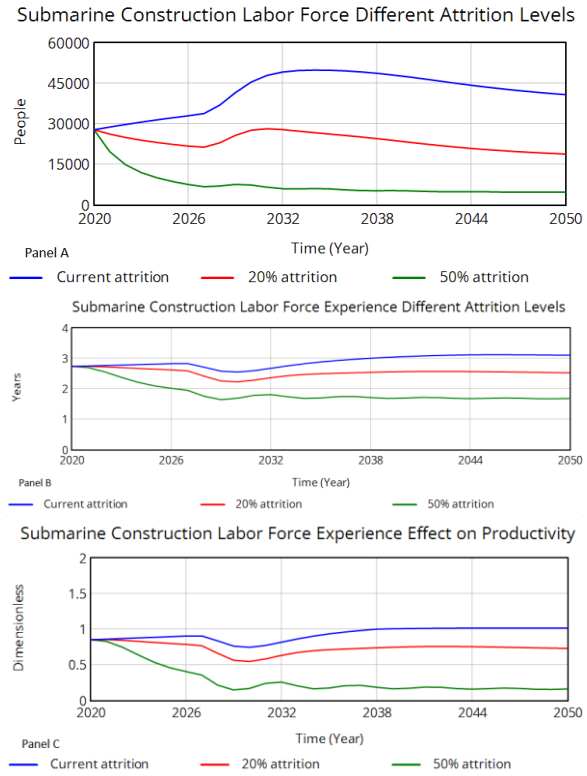

Figure 12. Effects of Increased Attrition on Workforce Level, Experience and Productivity.

Figure 12 shows the effects of twenty percent and fifty percent attrition in the construction labor force. Panel A shows the effects on the number of workers. By 2050, with twenty percent attrition, the workforce drops from roughly 23,000 to just under 19,000. With fifty percent attrition, by 2050 the workforce has fewer than 4,600 workers.

Panel B in Figure 12 shows the drop in average experience. Under both the current policy and with twenty percent attrition, average experience is roughly 30 months. If attrition rises to fifty percent, experience level drops to twenty months.

Panel C shows the effects of attrition on the productivity of the workforce. By 2050, productivity is a little more than seventy percent for both the current policy and twenty percent attrition. But for fifty percent attrition, productivity drops down to roughly sixteen percent.

Increased Attrition from Overhaul Labor Force

Increased attrition has also been a problem among the workforce charged with submarine maintenance and repair (Hendrix, 2024). Figure 13 on the next page shows the effects of twenty percent and fifty percent attrition in the overhaul labor force.

Panel A shows that with twenty percent attrition the number of overhaul workers drops to a level slightly more than half the number under the current attrition level. It also shows that fifty percent attrition drops the number of overhaul workers by approximately eighty percent. Panel B shows that with twenty percent attrition average experience drops from thirty-six months to

just under thirty months, but drops to twenty months with fifty percent attrition. Panel C shows the resulting effects on productivity; with twenty percent attrition productivity drops by about a third. With fifty percent attrition, it drops by eighty-five percent.

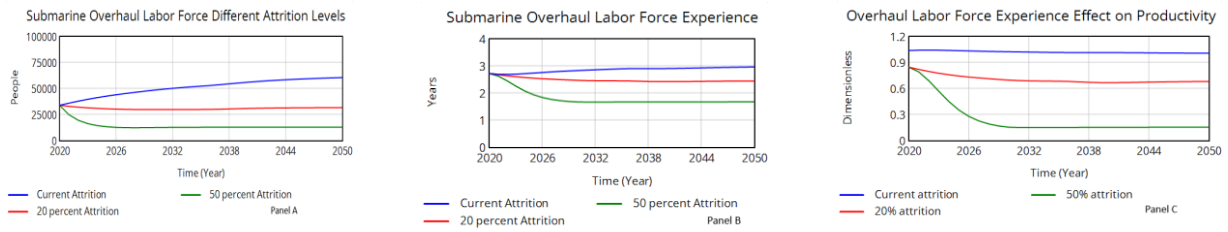

Figure 13. Effects of Higher Attrition on Overhaul Labor Force Size, Experience and Productivity

Increased Hiring of Construction Labor Force

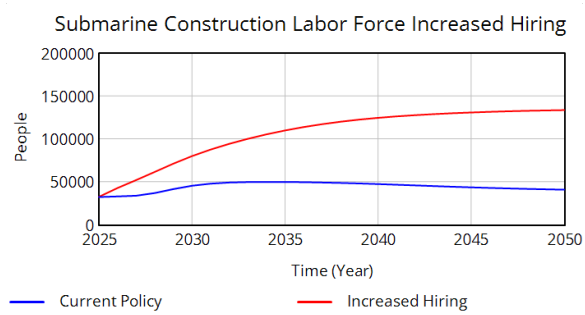

Figure 14. Effect of Hiring an Additional 10,000 Construction Workers per Year between 2025 and 2050

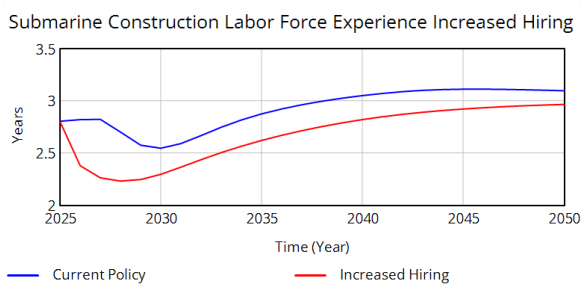

Figure 15. The Effect on Experience of Hiring an Additional 10,000 Construction Workers per Year between 2025 and 2050

The Navy estimates that, to succeed in meeting its submarine manufacturing objectives, its contractors will have to hire close to 140,000 new employees over the next twenty-five years (Wilson, 2023). Figure 14 shows the effect of hiring an additional 10,000 employees per year between 2025 and 2050. This policy results in approximately 135,000 employees by 2050.

However, there is a price to pay for the larger workforce: reduced experience. Figure 15 shows how the large number of inexperienced workers hired under this policy results in a workforce less experienced (red curve) than the one under the existing policy (blue curve).

Increased Hiring of Overhaul Labor Force

Wilson (2023) quotes the Executive Director of Strategic Submarines as saying that submarine contractors charged with overhauls of submarines would need an additional 40,000 workers over the next twenty-five years. Figure 16 shows the results of a simulation where overhaul contractors hired an additional 4,200 workers per year over that period. By 2050, their labor force is just under 100,000.

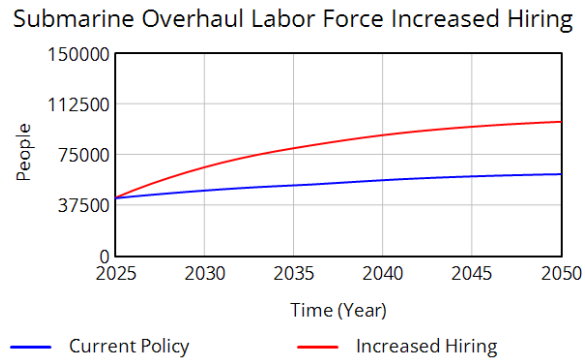

Figure 16. Effect of Hiring an Additional 4200 Overhaul Workers per Year Between 2025 and 2050

As was the case with construction workers, the trade-off of increased hiring of overhaul workers on a large scale is reduced experience, as shown in Figure 17 on the next page.

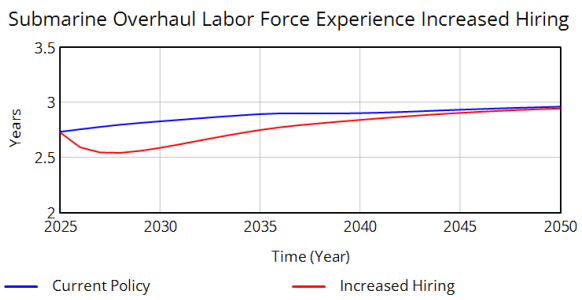

Figure 17. The Effect on Experience of Hiring an Additional 4,200 per Year between 2025 and 2050

However, this group, after a sizable drop in the early years of this period, gradually recovers to the same experience level as the current policy.

Better Training of Incoming Workforces

The model's current policy assumes that new hires have six months of experience. Figures 18 and 19 show the results of a policy where new workers are trained before hiring, such that they join their respective workforces with one year of experience. Figure 18 shows that better trained submarine construction workers come near to closing the experience gap in roughly five years, and completely close it by the end of the period. Figure 19 shows that better trained submarine overhaul workers close the experience gap in roughly seven years, and then exceed the current policy's average overhaul experience by the end of the period.

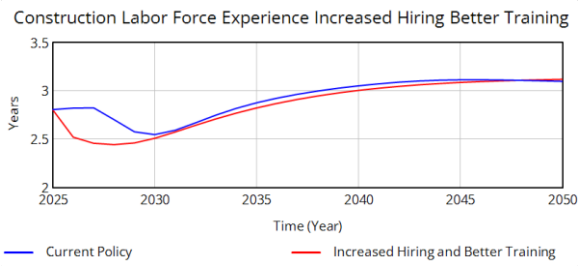

Figure 18. The Effect on Experience of Hiring Better Trained Construction Workers an Additional 10,000 per Year between 2025 and 2050

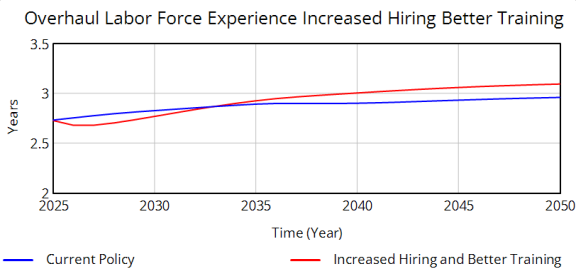

Figure 19. The Effect on Experience of Hiring an Additional 4,200 Better Trained Overhaul Workers per Year between 2025 and 2050

"Best Policies" Combined

From the previous policy experiments, we can discern a mix of worthwhile policies:

- Continuing the current production policy that leads to three attack submarines manufactured per year by 2050
- Overhaul time of one year for attack subs
- Overhaul time of sixteen months for the new ballistic missile submarines
- Maintaining the current realistic worker attrition rates of no more than ten percent
- Hiring pulses of 10,000 for construction and 4,200 for overhaul workers each year over the next twenty-five years
- Better workforce training

Figure 20 on the next page shows the results of a simulated run containing all six of these worthwhile policies. Panel A shows that, compared to the current policy, the combination of

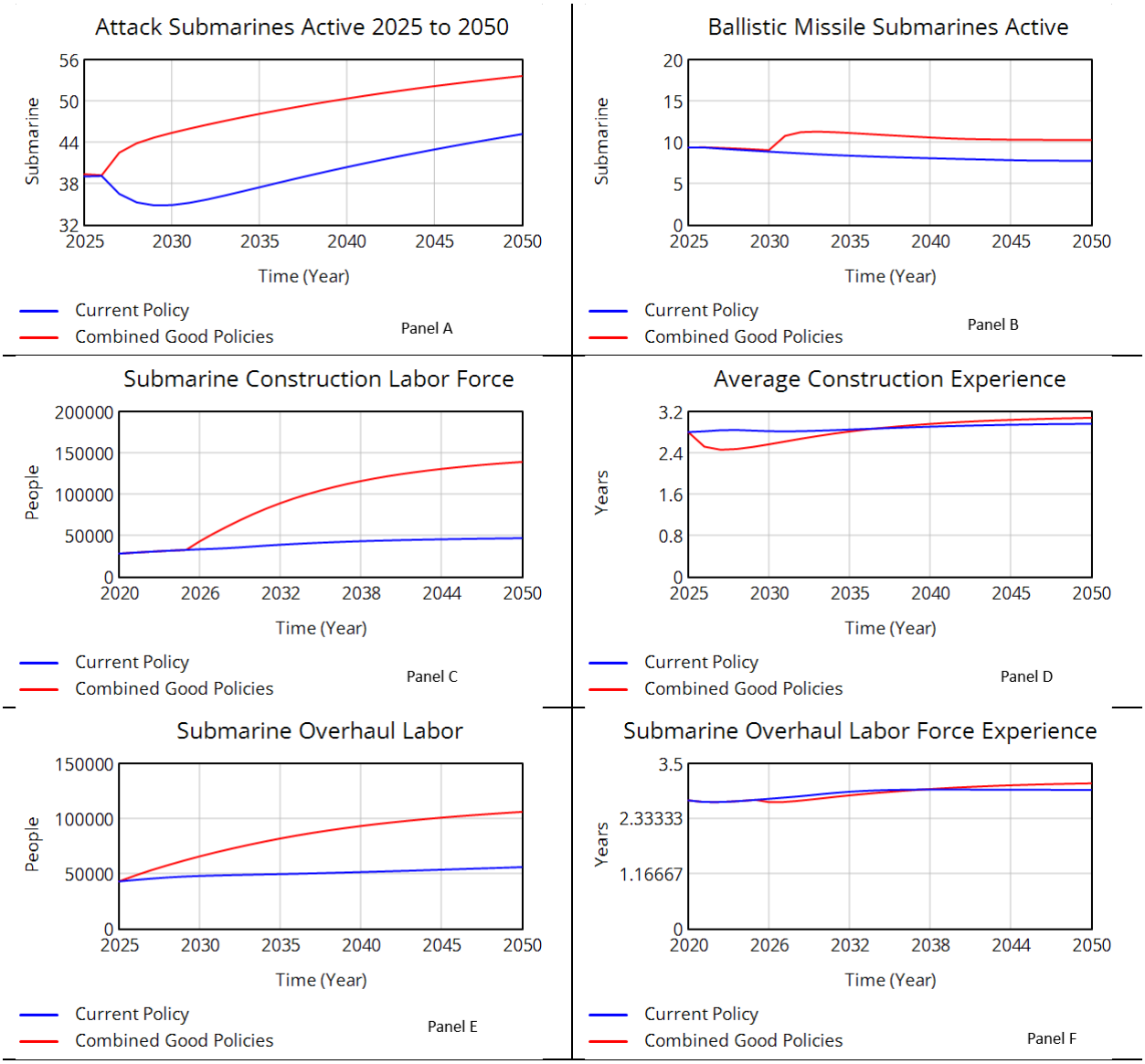

Figure 20. Effects of Combined Good Policies on U.S. Navy Submarine Fleet and Workforces

worthwhile policies gets the U.S. Navy much closer to its goal of fifty-three active attack submarines. Panel B shows the combination policies are much likelier to lead to the Navy's reaching its goal of ten active ballistic missile submarines. Panel C shows the construction workforce reaching a much more robust total of just under 140,000 workers, while Panel D illustrates that, after a brief dip, the experience level of the construction workforce actually slightly exceeds the level under the current policy. Panels E and F show a similar pattern for the overhaul workforce: a workforce of roughly 106,000 and an experience level slightly higher at the end of the period when compared to current policy.

Limitations of the Present Study

Beyond the difficulty in finding good data on the number, over time, of construction and overhaul workers in the submarine industrial base, the present model has some limitations. One is minor: there are several different "classes" of both attack and ballistic missile submarines, but the author concluded that, for the purposes of showing the structure of the U.S. Navy's submarine fleet, that level of disaggregation was not necessary. The study might also have added more detail to the overhaul infrastructure by explicitly adding the number of existing, and potential future, drydocks. However, the author felt that using the overhaul period as a proxy was sufficient to make the necessary points. Another potential weakness was that the construction and overhaul workforces might each have been disaggregated into two stocks—workers in training, after being hired, flowing into full-fledged workers. However, the author chose to start with the simpler version of the stock management problem, and that, by manipulating the amount of experience by incoming workers, proved to be sufficient for what the paper sought to achieve. Lastly, no data were available to help formulate the two non-linear functions: "Effect of Construction Productivity on Construction" and "Effect of Overhaul Productivity on Overhaul." Instead, the author created a plausible upward-rising function for "Effect of Construction Productivity on Construction," so that rising productivity led to higher construction. For "Effect of Overhaul Productivity on Overhaul," the author created a plausible downward-sloping function, so that as productivity rose, overhaul time decreased.

Conclusion

The structure of the U.S. Navy's submarine fleet and its accompanying industrial base for construction and overhaul are important, and complex. The stocks of the three kinds of submarines and their varying construction and overhaul periods were challenging to model, but the author believes that the model described in this paper succeeds in showing that structure. The Navy has projected that it needs more attack submarines, such that it has an active fleet of between fifty and fifty-five boats. It also projects the need for a more-or-less fixed number of advanced ballistic missile submarines (twelve, to be exact, with ten actives at any given time) and guided missile submarines (four, with three actives at any given time). The model in this paper captured the historical ups and downs of the submarine fleet's size, and ran several simulated scenarios for the future through 2050. The resulting best combination of policies seems to be as follows:

- Continuing, and achieving, the current production policy that leads to three attack submarines manufactured per year by 2050
- Achieving an overhaul time of one year for attack subs
- Achieving an overhaul time of sixteen months for the new ballistic missile submarines

- Maintaining the current realistic worker attrition rates of no more than ten percent
- Hiring pulses of 10,000 for construction and 4,200 for overhaul workers each year over the next twenty-five years, even though this might dilute the experience level of the workforces
- Better workforce training, to offset the dilution of experience level.

The Navy appears to be trying to do things very similar to these recommendations. The way is clear for them, but the implementation, as always, will be challenging.

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