DEPARTMENT OF THE NAVY
Science and Technology Board

Enhancing Surface Ship Maintenance Processes for Increased Availability

Final Report
December 2024

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DEPARTMENT OF THE NAVY
SCIENCE AND TECHNOLOGY BOARD
1000 NAVY PENTAGON
WASHINGTON D.C. 20350-1000

MEMORANDUM FOR THE SECRETARY OF THE NAVY

SUBJECT: Enhancing Surface Ship Maintenance Processes for Increased Availability

U.S. Navy ships spend ten times more time for maintenance in shipyards than their commercial equivalents. A 2017 Government Accountability Office (GAO) study of the previous 15 years found that the Navy achieved its maintenance goal for carriers only 47% of the time, and for submarines only 24% of the time. After expressing distress about these results, the Navy's performance over the next three years declined: aircraft carriers met maintenance goals 44% of the time and submarines only 15% of the time.[1] Since 2021, the scheduled duration of destroyer maintenance availabilities has been more than 20% above plan.[2] For all surface forces, maintenance has taken more than 25% of time beyond plan.

These failings are consequential. The first GAO study calculated that delays cost over 20 years of carrier and submarine deployment time. We calculate that if we reduced the time in maintenance and modernization of every surface combatant by one month every three years, we would gain about six more surface combatants ready for deployment. Going further, should Navy destroyers (DDG) require "only" five times more yard maintenance than commercial ships, the number of destroyers available for deployment would increase by more than 29%; more than 11 additional DDGs.

Many factors contribute to our failings. Navy ships are much more complex than commercial ships; schedules are disrupted by crises that extend deployments; we keep ships in service almost twice as long as their commercial counterparts; in their initial design, commercial ships put more priority on maintenance; foreign yards have abundant cheaper labor with more consistent demand and more competitive pricing; the U.S. Navy has organizational complexities and priorities that increase the cost of maintenance, etc.

Because the problem is complex, its solution requires multiple actions. We believe, however, that six initiatives would be especially productive. Further, we believe these initiatives, if applied initially to the surface fleet would have the most near-term effect. These are:

1. Accelerate efforts to create a digital thread for U.S. Navy ships.
2. Digitize shipyards.

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[1] These numbers were pointed out in O'Connell [Cross Navy Availability Optimization for the Nuclear Fleet - presentation to ASN(RDA) on 3 June 2024]. They were drawn from 2000-2016: Aircraft Carriers: 47% (25/53) Completed on time; Submarines: 24% (42/173) Completed on time; GAO, Navy Shipyards: Actions Needed Improve Poor Conditions that Affect Operations GAO-17-548 (Washington, D.C.: Sep. 2017)
2015-2019: Aircraft Carriers: 44% (8/18) Completed on time; Submarines: 15% (5/33) Completed on time 6,296 days Maintenance Delay; GAO, Navy Shipyards: Actions Needed to Address the Main Factors Causing Maintenance Delays for Aircraft Carriers and Submarines, GAO-20-588 (Washington, D.C.: Aug. 20, 2020)
[2] For DDG's from FY21-24, approximately 8 months on average, but the amount of time required to complete the availabilities has been about 9.8 months on average. [CNRMC email of 20 July 2024]

3. Construct digital twins of ships and of shipyard maintenance activities.
4. Establish an executive who is accountable and empowered to oversee maintenance.
5. Charge that executive with establishing a small number of metrics as incentives and means of judging maintenance performance.
6. Support the accountable executive by allocating additional funding to achieve these priorities and to include commission studies, tests, and sprint programs with third party evaluation of results.

While this report is focused on surface ship maintenance, many of the findings and recommendations are applicable across the fleet. The key findings are described in Appendix A and are based on the engagements with stakeholders and experts listed in Appendix B; the recommendations are presented below.

Recommendation 1: Accelerate efforts to create a digital thread for Navy ships.

At present, information about ship maintenance is spread over multiple independent, inconsistent, opaque and often lagging data systems.[3] A digital thread capturing data from a ship-based distributed digital infrastructure would present a comprehensive and constantly updated picture of a ship's systems status and performance in the same manner as the display on the dashboard video screen of a modern automobile provides information about the engine, tires, and other systems. However, a ship's digital thread designed for the Navy's maintenance and modernization enterprise would provide much more detailed information about many more systems. It would provide an accurate and up to date single source of truth across the many independent organizations and Information Technology data systems engaged in ship maintenance and modernization.

A digital thread would immediately inform ship maintenance at sea, empowering reliability-based maintenance by permitting unintrusive and continuous assessment of a ship's equipment and structural health. In port and in overhaul it would greatly improve troubleshooting, scheduling, provisioning, and execution. It would improve prediction of spare parts requirements both at sea and for yard maintenance. A mature system of digital threads for ships should be able to assess 90% of a ship's condition prior to a maintenance availability contract award, thereby enhancing availability of spare parts and the efficiency of parts supply. It could also provide a foundation for developing web-based, virtual reality and artificial intelligence assistance that could multiply the capabilities of ship personnel for on-board repair. And it would facilitate the use of additive manufacturing as recommended in another report from this board.

Secretarial leadership is required to achieve these rewards. We recommend directing NAVSEA to identify a program for deploying a robust digital thread within 12 months for at least two ships in their maintenance phase,[4] with a follow-on plan for scaling to the entire surface

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[3] GAO-22-104510, NAVY SHIP MAINTENANCE: Actions Needed to Monitor and Address the Performance of Intermediate Maintenance Period.

[4] The DoN has ongoing digital thread projects, notably including a Ships Maintenance Data Improvement Initiative (SMDII) led by Naval Surface Warfare Center (NSWC) Corona and the Naval Maintenance, Repair, and an Overhaul (N-MRO) program being developed by Program Executive Office for Manpower, Logistics and Business Solutions (PEO MLB) Logistics Information Technology Program Office (PMW 200).

combatant force. An ambitious but feasible target would be to establish digital threads for 50% of DDG 51s by 2030 and for 90% of surface combatants by 2035.

Recommendation 2: Digitize shipyards to improve maintenance and planning.

Extensive work by the chief digital transformation office has highlighted how Navy shipyards are crippled by paper-based information systems. Among other things they calculate that more than 100,000 "data critical pieces of paper" are required in the course of a submarine overhaul, that two dozen different program offices have critical roles in this maintenance effort, that in a carrier overhaul a hundred thousand dollars is expended every workday on manpower searching for required parts that cannot be located, and that each office's plan is often premised on inputs that other offices are not planning to provide at the expected time.[5] For instance, their preliminary work uncovered an expectation of delivery of a dry-dock approximately a year earlier than it would actually have been provided.[6] They make a credible case that a "digital hub" could correct these deficiencies with a three year effort. We think their recommendations are well warranted and would put the Navy on track to "smart shipyards" (their phrase).

While the chief digital transformation office focused on our public yards, the Navy should incentivize private yards that conduct surface ship maintenance to similarly employ digital technologies that improve efficiency and throughput.

Recommendation 3: Construct Digital Twins of Ships and of Shipyard Maintenance Activities

A digital twin is a digital (virtual) representation of a physical product or system maintained throughout its service life. A digital twin includes digital models and associated digital environments that enable prediction of performance through simulation. The digital twin is kept aligned with systems through continuous or periodic updates provided either manually or automatically via direct measurements on the system. The purpose of a digital twin is to provide insight in support of making decisions.

By establishing digital threads on ships and digital information systems in shipyards, Recommendations 1 and 2 pave the way for modeling the two systems together. With these data inputs digital twins have the potential to:

- Support forensic analysis to determine causes of failure of equipment (principally on ships) and of processes (both on ships and in yards).
- Detect failures by comparing real time measurements with those predicted by the digital twin.

[5] O'Connell [Cross Navy Availability Optimization for the Nuclear Fleet -presentation to ASN(RDA) on 3 June 2024].

[6] "[T]he USS MISSISSIPPI (SSN 782) was scheduled to arrive for a maintenance availability ~1 year before dry dock upgrades were scheduled to be finished, and two years before the Waterfront Production Facility (WPF) was scheduled to be completed, resulting in an unexpected one-to-two-year delay for the SSN 782's availability…. Once identified using the I2MP process, these issues were corrected." O'Connell [Cross Navy Availability Optimization for the Nuclear Fleet – presentation to ASN(RDA) on 3 June 2024].

- Assess the current condition of equipment and systems.
- Predict performance under anticipated future conditions[7] and hypothetical stressing conditions.
- Simulate and compare potential courses of action.

The feasibility and rewards from digital twins have been demonstrated for some combat systems,[8] and for some logistics problems.[9] Digital twins for ships are being developed by NSWC Carderock and NSWC Philadelphia. An expanded effort that integrates models of all critical shipboard systems is warranted. The Navy should build on existing projects to create a validated family of models and associated simulation environments comprising a comprehensive total ship digital twin. The development and maintenance of digital twin should be accomplished by establishing an enduring program of record.[10]

Recommendation 4: Establish an accountable and empowered executive to oversee maintenance.

The CNO should designate an accountable flag officer as a supported commander and the leader of the Surface Ship Maintenance Enterprise (SSME). The CNO should further designate appropriate supporting commanders.

As the accountable officer fulfilling the role of the business executive, the leader of the SSME should identify and be held accountable for achieving some clearly defined and publicly articulated goals. We suggest some metrics and goals in the next recommendation.

We recommend the SSME embrace the following priorities and develop plans for achieving them:

- Keep Lead Maintenance Activity (LMA) responsibilities within the Government. The current common practice of assigning LMA responsibility to the private shipyards with fixed price contracts often results in schedule delays due to poor integration of work from outside organizations such as Alteration Installation Teams (AITs).
- Standardize RMC organizational structures; ascertain and advocate for appropriate resources and workflows.
- Actively manage workforce development in applicable technical and program management competencies.

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[7] Among other things, we should routinely predict whether equipment will be corrective maintenance free prior to the next scheduled, appropriate, maintenance availability.
[8] The NAVAIR Airborne Electronic Attack Systems Program Office is employing a digital twin for the ALQ-99 Tactical Jamming System (TJS). A digital twin is also being employed for the Aegis Combat System. In 2021 VADM Galinis stated "where we've had problems with the combat systems or had to provide software upgrades or updates, that digital twin has been very helpful in allowing us to quickly test those software changes and get them deployed to the fleet."
[9] Digital twins have been developed for the Ford class CVN weapons elevators; these digital twins were critical in placing the advanced weapons elevators into operation.
[10] N-MRO program being developed by PEO MLB's Logistics Information Technology Program Office (PMW 200) is addressing application of digital threads within the Navy; expanding scope to include digital twins is possible and should be examined.

- Work with acquisition program managers to correct provisioning shortfalls.
- Assign ship acquisition program managers the responsibility to deliver fully functional digital threads and digital twins with every delivered ship.
- Limit the scope of maintenance and modernization availabilities to enable better schedule adherence. Experience has shown that limiting work assigned to an availability to that which can be accomplished in less than one-year results in a much higher probability of on-time completion than if the assigned work results in scheduled durations beyond one year. Two availabilities of duration less than one year can result in less time in maintenance than if the combined work is assigned to a single availability. [11]

Recommendation 5: Charge the accountable executive with establishing a small number of metrics as incentives and means of judging maintenance performance.

Numerous metrics assess maintenance performance. The most significant metric is the Days of Maintenance Delay (DoMD) which reflects the number of days that an availability extends beyond the completion date stated at the start of the availability. Other metrics of note include percent of on-time delivery, per cent new work, per cent growth work, long lead material delivered 30 months prior to the start of a maintenance availability (A-30), and Request for Contract Change (RCC) cycle time.

We believe that metrics can be created or revised to better facilitate oversight and, most importantly, to incentivize behavior. The system badly needs goals, plans to reach these goals, benchmarks en route and accountability for results. The impact of goals and metrics on organizational behavior should be explored through techniques such as acquisition wargaming. We suggest the following as examples of metrics and goals that should be considered:

1. The number of months in the Optimized Fleet Response Plan (OFRP) Maintenance Phase should be reduced to no more than 9 months out of every 36 months by 2028 and no more than 7 months out of every 36 months by 2030. While 9 months is the existing target for maintenance phase duration, on average, naval ships exceed this target. Most commercial ships have an equivalent maintenance period of one month or less every 36 months; achieving 7 months for naval ships should be achievable if best practices are employed. Reducing time in the maintenance and modernization is critical to having more ships available for deployment.
2. By 2026, 90% percent of required work (manhours) should be identified at the start of maintenance availabilities. Historically, budgets have assumed 90% work identification, but in several recent availabilities, the required work identified at the start of an availability has been as low as 50%. (This is largely attributable to surprises resulting from incomplete ship condition assessments, "growth work" discovered post-initiation of the availability, and unplanned AIT integration.) Lower work identification results in critical underfunding and insufficient scheduling of availabilities.
3. By 2028, 90% of repair parts for a maintenance availability should be available through NAVSUP/DLA. Supply systems now commonly provide fewer than 50% of the parts used in a maintenance availability. The digitization recommendations above should

[11] GAO-20-257T, NAVY MAINTENANCE: Persistent and Substantial Ship and Submarine Maintenance Delays Hinder Efforts to Rebuild Readiness

greatly improve ability to accurately forecast parts usage and maintain adequate repair parts inventories. To further facilitate repair parts availability, ship acquisition programs should complete all integrated logistics support activities before turn-over of ship responsibility to the in-service program office.

4. Reduce parts cannibalization to below 10% of FY24 level by 2028 and below 2% of FY24 level by 2030. Greater availability of parts through the supply system and additive manufacturing should enable eliminating cannibalization in most cases. Cannibalization increases workload and downtime for the ships providing parts. The commercial marine industry does not resort to cannibalization.
5. Logistics Delay Time. Fewer than 10 days of availability completion date slippage from original contract date due to parts availability by 2028, and 0 days by 2030. Late identification of work, additional growth work identified once the availability commences, and the inability to rapidly procure required repair parts combine to delay the completion of availabilities; work cannot complete until repair parts are received.
6. Percent successful completion of System Operational and Verification Tests (SOVTs) at the end of sea trials following maintenance availabilities. 95% by 2028 and 100% by 2030. Having systems without successful SOVT completions at the start of the OFRP Basic Phase can lead to reduced training effectiveness and lower ship readiness.
7. Number of days surface combatants are not available due to maintenance during the OFRP training and sustainment phases. Goal should be to halve the number of days currently experienced by the fleet. As part of this goal, improve Hull, Mechanical, and Electrical (HM&E) system reliability (mean time between failure - MTBF) by 2% annually.

Recommendation 6: **Support the accountable executive by allocating additional funding to achieve these priorities and to include commission studies, tests, and sprint programs with third party evaluation of results.**

We anticipate that the accountable executive will assess ongoing programs, identify gaps, and propose initiatives to fill the gaps to the appropriate resource sponsor. There are several ongoing investments to attempt to improve/optimize ship maintenance improvements. The SSME should review pilot projects and other resources aligned toward improvements in ship maintenance and assign execution responsibility for studies, tests and pilot projects supporting that demonstrably contribute to achieving maintenance metrics developed in accord with recommendation #5. The Navy's budget should prioritize these investments. We estimate that an additional $150M will need to be applied toward digital thread and digital twin pilot projects to enable measurable improvement. In the near term, below threshold reprogramming authority will be required for funding FY25 projects.

Appendix A

Stakeholder and Maritime Industry Discussion Key Findings

The recommendations detailed in this report stem from key findings identified during our stakeholder and maritime industry discussions; these key findings include:

1. Operational days lost to maintenance and modernization. The major contributors to operational days lost due to do maintenance and modernization are:

    a. Condition Assessment.
    b. Parts Availability.
    c. Reliability and Maintainability.
    d. Knowledge management, Planning and Contracting.

2. SSME leadership. SSME leadership and resultant accountability requires clarification.

3. Digital Thread. An end-to-end integrated digital thread is a long-term aspirational goal provided by PEO-MLB. However, near term program performance is handicapped with a patch-work architecture. The digital thread is a key foundational capability needed to improve overall performance. NAVSEA leadership has stated that an enterprise approach to implementing a digital thread is necessary and requires the Navy to commit resources (both organizational and funding) on par with those provided to Project Overmatch; Project Overmatch is a high priority initiative focused on ensuring operationally relevant data is available at the tactical edge, when and where required.

4. Digital Thread. The commercial maritime industry has set a precedent for the implementation of a digital thread as part of a live operations center. While the U.S. Navy uses integrated operations centers for military operations, the U.S. Navy does not currently have this capability for support operations.

5. Digital Twin. In other complex systems in industry, the employment of digital twins has proven to result in favorable ROIs and improve performance.

6. Condition Assessment. Lack of a reliable ship material condition status in the life cycle impacts proper planning and contract execution.

7. Parts Availability. Unavailability of repair parts and inadequate provisioning program performance lead to cannibalization, poor use of NAVSUP capabilities, and inadequate inventories of repair parts; these practices result in poor availability performance.

8. Reliability Programs. Total ship proven reliability programs have largely been abandoned over the last thirty years; the lack of these programs is impacting fleet wide Operational Availability (Ao).

9. Contracting strategy. Navy contracting strategies have resulted in private sector maintenance contractor behavior and performance that are inferior to the gold standard equivalent in commercial ship maintenance. The Navy's approach to integrating Alteration Installation Teams (AITs) into availabilities has added complexity to contracting and availability execution.

10. Availability Planning. The current Navy availability planning process is supported by inadequate condition assessments results in significant growth work resulting from the open and inspect process, which further cascades in not having all the necessary parts to execute the availability. The existing methods have only been successful in identifying about 50% of the required work at the start of a maintenance availability; the Navy should establish as a goal to identify 90% of the required work at the start of a maintenance availability (no more than 10% of the required work identified as growth) no later than 2030.

11. Metrics. The maintenance community employs metrics to track performance; the most notable one is Days of Maintenance Delay (DoMD). DoMD is defined as the number of days that an availability extends beyond the originally established end of the availability or completion date at the start of the availability. While DoMD has proven useful, it does not provide sufficient insight to focus investments for improvement. Other examples of metrics include percent of on-time delivery, per cent new work, per cent growth work, long lead material delivered at A-30, and Request for Contract Change (RCC) cycle time.

Other possible contributing factors that may be impacting the ability to complete maintenance and modernization availabilities on time include:

a. Expertise of maintenance workforce
b. Lack of repair facilities
c. Slow adoption of maintenance technology
d. Ship's crew operating equipment in a manner that results in more than necessary maintenance
e. Rework
f. Damage of equipment during maintenance availabilities
g. Equipment Testing
h. Tagout procedures
i. Hazardous Material Management

These possible contributors have not been confirmed through stakeholder discussions; they should be investigated further.

Appendix B

List of Engagements

	Date	Location	Organization	Name/Title
1	20 Nov 2023	Washington, DC (Pentagon)	N80	RADM Brad Skillman, OPNAV N80, Director of Programming
2	26 Jan 2024	Norfolk, VA	MSC	Andy Busk – Engineering Director
3	26 Jan 2024	Norfolk, VA	MARMC	CAPT Young – Commanding Officer
4	29 Jan 2024	Makapala, HI	PACFLT HQ	VADM Blake Converse – Deputy Commander, U.S. Pacific Fleet (PACFLT) RDML Daniel Ettlich – Director, Fleet Maintenance, PACFLT Mr. Dave Adams – Director, Warfighting Effectiveness, Assessments, and Readiness (N9), PACFLT
5	29 Jan 2024	Camp Smith, HI	INDOPACOM	ADM John Aquilino – Commander, U.S. Indo-Pacific Command
6	30/31 Jan 2024	Pearl Harbor, HI	PHNSY	Shayla Deitch – Innovation Program Manager CAPT Richards Jones – Commander, PHNSY & IMF
7	12 Feb 2024	Washington Navy Yard	SWRMC	Ms. Monique Kadmiri – Chief Engineer SWRMC
8	04 Mar 2024	San Diego, CA	SWRMC	CAPT John Bauer – Commanding Officer
9	04 Mar 2024	San Diego, CA	PEO C4I	CAPT Raphael Castillejo – program Manager
10	05 Mar 2024	Coronado, CA	COMNAVSURFOR	CDR Arthur Anderson – ROC Lead CDR Leon Faison – FMO Rebecca Boxerman – ONR Global Science Advisor
11	05 Mar 2024	San Diego, CA	GD-NASSCO	Brett Hershman – Director, Business Dev. and Government Relations
12	05 Mar 2024	San Diego, CA	BAE Systems	Ahmed Elshikh – Director I, Programs Arthur Fairwell – Director II, Strategic Operations
13	06 Mar 2024	Corona, CA	NSWC Corona	Ms. Diane Costlow – SES, Technical Director Peter Ku – AR00 Acquisition & Readiness Assessment Dept. Chief Engineer

14	13 Mar 2024	Miami, FL	Carnival Cruise Line	Lars Ljoen – Chief Operations Officer William Burke – External Affairs Advisor Mark Jackson – Senior Vice President, Technical Operations Martina Gallus –Vice President, Technical Operations Domenico Rognoni – Chief Marine Officer
15	14 Mar 2024	Philadelphia, PA	NSWC Philadelphia	Mr. Seth Burmaster – Department Head, Propulsion Systems, Naval Surface Warfare Center Philadelphia Division (NSWCPD), NAVSEA
16	18 Apr 2024	Washington, DC (Pentagon)	CNSF	VADM McLane – Commander, Naval Surface Forces
17	21 May 2024	Virtual – Microsoft Teams	NAVSUP	Ms. Karen Fenstermacher – Executive for Strategic Initiatives Mr. William Davis – Director, Strategic Supplier Management
18	23 May 2024	Virtual – Microsoft Teams	FFC/PEO MLB (NMRO)	RDML Diana Wolfson – Director, Fleet Maintenance Jim Edwards – NMRO Lead
19	03 Jun 2024	Virtual – Microsoft Teams	NAVSUP	Ms. Lynn Kohl – Vice Commander, Navy Supply Systems Command
20	05 Jun 2024	Virtual – Microsoft Teams	PEO-MLB, LogIT	Mr. Joe Willette – Program Manager
21	06 Jun 2024	Washington, DC (Pentagon)	Naval Aviation P2P	James Mosler – Director OPNAV Problem Solving & Process Improvement Office
22	17 Jul 2024	NSWC Carderock Division	CRMC SWRMC	Mr. Eric Lind – Executive Director, Navy Regional Maintenance Centers Ms. Monique Kadmiri – Chief Engineer SWRMC
23	29 Jul 2024	Washington, DC (WNY)	CNRMC	RADM William Greene – Commander, Navy Regional Maintenance Center and Director – Ship Maintenance, Modernization, & Sustainment
24	23 Aug 2024	Washington, DC (WNY)	NAVSEA	VADM James Downey – Commander, Naval Sea Systems Command
25	05 Sep 2024	Washington, DC (Pentagon)	OPNAV N9B	Mr. John Hootman Assistant Deputy CNO for Warfighting Requirements and Capabilities