NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

BETTER ESTIMATION OF COMPLETION TIMES FOR SHIPS UNDERGOING CNO AVAILABILITIES

by

Amy W. Lee

September 2022

Thesis Advisor:	Ronald E. Giachetti
Co-Advisor:	Paul T. Beery

This project was funded in part by the NPS Naval Research Program.

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC, 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** September 2022	**3. REPORT TYPE AND DATES COVERED** Master's thesis	
4. TITLE AND SUBTITLE BETTER ESTIMATION OF COMPLETION TIMES FOR SHIPS UNDERGOING CNO AVAILABILITIES			**5. FUNDING NUMBERS**
6. AUTHOR(S) Amy W. Lee			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. This project was funded in part by the NPS Naval Research Program.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

United States Navy (USN) surface ships must complete routine maintenance, repair work or upgrades in order to maintain operations to support the fleet. However, a large majority of planned maintenance availabilities exceed their schedule and consequently decrease their readiness to support the fleet and negatively impact ship readiness and operational availability. The USN uses an Availability Duration Scorecard (ADS) to manually determine surface ship maintenance durations, but it does not accurately capture the complexity of the work required. There is a need for more accurate predictions using ADS that include a detailed evaluation of work performed, to include the complexity of specific tasks. This thesis conducts an analysis of the tanks and voids maintenance activity duration estimates for three classes of USN ships. Regression analysis is conducted on ships where the availability duration substantially exceeded the ADS estimate. Regression shows no statistically significant relationship between the number of maintenance activities on tanks and voids and the total availability duration. Additionally, there is no statistically significant relationship between unplanned tanks and voids maintenance activities and the total availability duration.

14. SUBJECT TERMS availability, availability duration scorecard, CNO, maintenance, maintenance delay, on-time delivery, ship availability, ship maintenance, modernization, surface ships			**15. NUMBER OF PAGES** 71
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release. Distribution is unlimited.

BETTER ESTIMATION OF COMPLETION TIMES FOR SHIPS UNDERGOING CNO AVAILABILITIES

Amy W. Lee
Civilian, Department of the Navy
BS, Ohio State University, 2003

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
September 2022

Approved by: Ronald E. Giachetti
Advisor

Paul T. Beery
Co-Advisor

Oleg A. Yakimenko
Chair, Department of Systems Engineering

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

United States Navy (USN) surface ships must complete routine maintenance, repair work or upgrades in order to maintain operations to support the fleet. However, a large majority of planned maintenance availabilities exceed their schedule and consequently decrease their readiness to support the fleet and negatively impact ship readiness and operational availability. The USN uses an Availability Duration Scorecard (ADS) to manually determine surface ship maintenance durations, but it does not accurately capture the complexity of the work required. There is a need for more accurate predictions using ADS that include a detailed evaluation of work performed, to include the complexity of specific tasks. This thesis conducts an analysis of the tanks and voids maintenance activity duration estimates for three classes of USN ships. Regression analysis is conducted on ships where the availability duration substantially exceeded the ADS estimate. Regression shows no statistically significant relationship between the number of maintenance activities on tanks and voids and the total availability duration. Additionally, there is no statistically significant relationship between unplanned tanks and voids maintenance activities and the total availability duration.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

ADS	Availability Duration Scorecard
ASTM	American Society for Testing and Materials
AWP	Availability Work Package
BAWP	Baseline Availability Work Package
CASREP	casualty report
CCAMM	Corrosion Control Assessment Maintenance Manual
CG	Guided Missile Cruiser
CMAV	Continuous Maintenance Availability
CMP	Continuous Monitoring Program
CNO	Chief of Naval Operations
CNRMC	Commander, Navy Regional Maintenance Center
CSMP	Current Ship's Maintenance Project
DDG	Guided Missile Destroyer
D-Level	Depot level maintenance
DOD	Department of Defense
DSRA	Dry-Docking Selected Restricted Availability
EDSRA	Extended Dry-Docking Selected Restricted Availability
FDNF	Forward Deployed Naval Forces
HM&E	Hull, Mechanical and Electrical
I-Level	Intermediate level maintenance
JFMM	Joint Fleet Maintenance Manual
LCS	Littoral Combat Ship
LHA	Landing Helicopter Amphibious Assault Ship
LHD	Landing Helicopter Deck Amphibious Assault Ship
LPD	Landing Platform Dock Amphibious Assault Ship
LSD	Landing Ship Dock Amphibious Assault Ship
NAVSEA	Naval Sea Systems Command
NDE	Navy Data Environment
O-level	Organization level maintenance
PARM	Participating Acquisition Resource Manager

PE	Port Engineer
PMS 407	Surface Ship Modernization Program Office
PMS	Planned Maintenance System
RCM	Reliability Centered Maintenance
RMC	Regional Maintenance Center
SCN	Shipbuilding and Conversion, Navy
SEA21	Surface Ship Maintenance, Modernization and Support
SME	subject matter expert
SRA	Selected Restricted Availability
SURFMEPP	Surface Maintenance Engineering Planning Program
SWRMC	Southwest Regional Maintenance Center
T&V	tanks and voids
TDMIS	Technical Data Management Information System
TFP	Technical Foundation Paper
TSRA	Total Ship Readiness Assessment
TYCOM	Type Commander
USN	United States Navy

EXECUTIVE SUMMARY

United States Navy (USN) surface ships must undergo routine maintenance, repairs, or upgrades in order to maintain operational readiness. A majority of planned maintenance availabilities exceed their allotted schedule and consequently decrease their readiness to support fleet operations. This impacts ship readiness and operational availability. The USN uses an Availability Duration Scorecard (ADS) to manually determine surface ship maintenance durations for all Chief of Naval Operations (CNO) availabilities. The ADS uses data sources and historical ship availability data to predict the timelines required to complete maintenance activities for each maintenance availability. The scorecard was intended to calculate effective on-time delivery and generate more predictable timelines for the shipyards.

Nevertheless, surface ships continue to exit their availabilities late. Most delays are attributed to unplanned maintenance or items added to the work scope. The estimates seem to be based on a scope of work, which does not capture the complexity of the work required nor the additional work discovered during the maintenance process. There is a need for more accurate predictions of ship availabilities.

The thesis gathered data from several planning sheets for ships, all of which exited their availability late. These ships were selected since there was access to initial planning data before the start of the availability and the final planning data after the completion of their availability. Each planning sheet was filtered to focus on tanks and void maintenance activities. Once the number of tank activities were determined, the author compared the maintenance day estimates from the planners and ADS against the actual days executed.

A regression analysis was conducted to determine if there is any correlation with the number of tanks activities, the addition of new maintenance activities, and the days required to complete the maintenance. The data did not show any linear trends based on the number of activities or how the addition of new activities affected the total days to execute the work. There is also no evidence suggesting that either planners or ADS

provided a better duration estimate. The results are inconclusive since there is no relationship between the variables.

This analysis only used 10 hulls, which included cruisers, destroyers and amphibious ships. The recommendation is to conduct a more robust analysis with more hulls for each class of ship. More data collected on each class of ship will enable a more comprehensive analysis that may result in more actionable recommendations to improve the duration analysis estimation process.

ACKNOWLEDGMENTS

I would like to express my deepest appreciation, without whom I would not have been able to complete this thesis:

My thesis advisors Professor Ron Giachetti and Professor Paul Beery for their assistance and guidance on this topic.

The subject-matter expert of Memo Valdez. I am sincerely thankful for working with someone who is passionate in his role and his efforts to support the fleet. This thesis would not have been possible without his expertise and background on this topic.

I also want to express my sincere gratitude to Vince Leddy. You have always given me a perspective that I will never learn from a book.

A big thank you to Ricky Kong. You have me given me consistent support throughout this crazy journey.

And finally, to my two minions Jacob and Wendy. My apologies for the grumpiness of the past two years. Your constant reminder to not give up is the reason I kept going. I hope this journey inspires you in your future endeavors.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

Navy ships require routine maintenance, repair work, and upgrades to sustain their role in fleet operations. These actions are performed during a maintenance availability, which is a scheduled period of time set aside for the ship to undergo depot-level maintenance in the shipyard. Unfortunately, a large majority of planned maintenance availabilities exceed their scheduled duration. Staying in the shipyard longer than planned means the ship cannot return to the fleet, consequently decreasing fleet readiness and negatively impacting operations.

The United States Navy (USN) uses the Availability Duration Scorecard (ADS) method to estimate ship maintenance availability durations. The ADS takes into consideration port capacities and previous ship maintenance availability data to estimate how long the maintenance work will take. This information is used by fleet commanders to distribute workload across all the shipyards and avoid creating a backup of ships waiting work completion.

This thesis analyzes the current process for estimating Chief of Naval Operations (CNO) availability durations, identifies possible causes of errors in the ADS estimates, and proposes improvements to CNO availability duration estimates.

This thesis consists of five chapters. Chapter I provides background information about shipboard maintenance. Chapter II focuses on the literature review. Chapter III presents the description of the research method. Chapter IV describes the analysis of the results. Chapter V presents conclusions as well as recommendations on future research.

A. MAINTENANCE BACKGROUND

The USN faces many challenges to maintain its surface combatant fleet. Tension exists in the Navy's budget between funding the acquisition of new ships and less eye-catching expenditures on maintenance of existing ships. Unfortunately, the USN has an aging fleet which requires increased costs to maintain. The Navy's estimated cost of lifetime maintenance for six classes of surface ships is now estimated at more than $100 billion higher than the initial development of the ship (Donnelly 2020). As the fleet continues to age, the costs will continue to increase each year the ships are in service.

When funds are not allocated to ship maintenance, then the Navy often defers needed maintenance to future years, which results in compounded costs. During a 2019 midyear review, the Navy determined it had incurred more than $3 billion in emergency costs (Larter 2019). Emergency costs include unplanned repairs or upgrades that add time to the nominal duration and need more funds than originally planned. This also included $1 billion in unfunded ship maintenance (Larter 2019). The Navy must prioritize issues that must be addressed, therefore deferring the remainder of the maintenance work to future maintenance availabilities, which will lead to more expensive repairs at the later date. Ship maintenance availability schedules that shift into the following year(s) also affect future ship schedules.

Maintenance describes the work conducted to keep something in acceptable operating condition by providing proper upkeep, repairs, upgrades, and corrections to ensure equipment and systems function as designed. Without crucial routine maintenance, complex systems can become costly to repair. Each component must be maintained to operate efficiently within the entire system. USN ships require routine equipment maintenance because hardware reliability decreases with age and use, negatively affecting system operational readiness. The Navy performs maintenance at specific time frames or equipment condition states to help ensure that systems, equipment, and components perform their intended function when required (DON 2015a).

USN maintenance philosophy is derived from the Reliability Centered Maintenance (RCM) process that analyzes requirements “to develop a maintenance program in an environment of uncertainty and with limited operating data” (Button 2015, 22). Maintenance actions fall into one of three types:

- Preventative: To minimize unsatisfactory conditions and conducted on a time or condition-based interval to prevent the breakdown of equipment and age-related failures (DOD 2014). Knowing that the light bulb typically burns out after 12 months of service and replacing the bulb at 11 ½ months is an example of preventative maintenance.

- Corrective: To correct unsatisfactory conditions. Corrective maintenance requires tasks performed to repair, restore, align or replace equipment. Performing corrective maintenance restores lost or degraded functions by correcting unsatisfactory conditions and can prevent any emergency related maintenance (DOD 2014). Changing a burnt-out light bulb is an example of corrective maintenance.

- Alterative: To eliminate unsatisfactory conditions by modification or upgrade (DOD 2014). Replacing the incandescent light bulb with an LED version is an example of alterative maintenance.

The Navy defines three levels of ship maintenance, which are:

- Organization level (O-level) maintenance is the lowest and most cost efficient maintenance, which is routinely conducted by ship's force. Each individual ship and crew is expected to be trained and self-sufficient to maintain equipment at the appropriate operating levels, perform specified planned maintenance, and perform corrective maintenance within their capability and capacity.

- Intermediate level (I-level) maintenance requires the assistance of technical representatives and/or contractors. During this period, planned and corrective maintenance is conducted as well as any emergent work beyond the capability of O-level maintenance.

- Depot level (D-level) maintenance is performed during a scheduled ship maintenance availability. During depot maintenance, the ship is not operational because it is in the shipyard.

B. SHIP AVAILABILITY

Navy ships go through regularly scheduled periods of maintenance, repairs, and upgrades during a scheduled period called an availability. Due to the extended period to complete the scheduled work, a CNO availability is a type of availability scheduled with CNO approval (Button 2015).

CNO availability maintenance requirements are documented with Ship Sheets (Button 2015). Ship Sheets list labor and material costs associated with availability maintenance requirements and identify the resources required to support the needed ship maintenance. These Ship Sheets are developed by comparing current conditions of the ship against Technical Foundation Papers (TFP). A TFP is a notional maintenance plan used to identify a long range maintenance schedules (NAVSEA 2017).

The maintenance conducted during the availabilities are what keep ships modern, operational, and habitable. "There are three types of maintenance availabilities: Chief of Naval Operations (CNO) Availabilities, non-CNO (TYCOM) Availabilities, and New Construction (SCN) Availabilities" (Button 2015, 23). The SCN availabilities can include Post Shakedown Availabilities (PSA) but will not be discussed in this thesis. A PSA is "assigned to correct deficiencies found during the shakedown cruise or [complete] other authorized improvements" (DON 2021, V-I-FWD-B-12).

One type of CNO availability is Selected Restricted Availability (SRA). An SRA is scheduled for repairing and making selected alterations by industrial activities, which includes specialized work such as welding, piping, and electrical. An SRA can coincide with I-level maintenance. The type of work conducted "includes tank preservation, propulsion, ship-system repairs and some enhancements to hull, mechanical, and electrical (HM&E) systems" (Button 2015, xiv). This type of availability is scheduled between major overhauls for those ships with extended operating cycles.

A Dry-Docking Selected Restricted Availability (DSRA) is scheduled for ships that require more substantial maintenance and requires the use of dry docks. The type of work conducted can include major repairs to HM&E systems. An Extended Dry-Docking Selected Restricted Availability (EDSRA) includes maintenance and modernization that cannot be completed in a regular DSRA. An EDSRA is typically scheduled to begin at the 192 month (16 year) mark of a ship's life (Button 2015).

A Continuous Maintenance Availability (CMAV) is accomplished on surface ships outside of scheduled CNO availabilities for standard periodic maintenance (DON 2021). These are short availabilities, typically three to six weeks, for surface ships and are scheduled once per non-deployed quarter when the ship is in port for at least three continuous weeks (DON 2021). CMAVs are for conducting inspections, performing condition-based upkeep, and accomplishing minor repairs.

A ship may have a large backlog of maintenance and modernization actions required. Due to budget constraints and/or schedule constraints, not all of them can be completed during the scheduled availability. Consequently, the Navy plans an availability to complete only a certain number of maintenance actions and modernization efforts. As ships continue to age, they will require more extensive midlife overhauls. Deferred maintenance of older ships will make it more expensive to complete later.

With the complexity of operating aging ships, the Navy must plan the work during the availability including estimates of the time and budget required for each work item. Naval Sea Systems Command (NAVSEA) is an organization that has various resources to support the Navy. Within NAVSEA, the Surface Ship Maintenance, Modernization, and Support (SEA21) group is responsible for the life cycle maintenance and modernization for surface ships as shown in Figure 1. In order to schedule extended maintenance periods, a planning tool is required to assist in establishing the estimated duration of the availability.

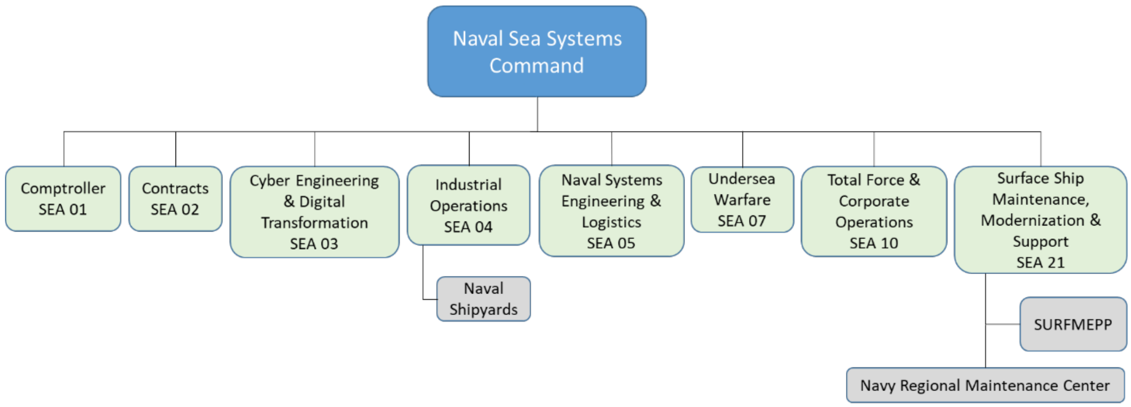


Figure 1. NAVSEA organization. Source: NAVSEA (2022).

C. DURATION ANALYSIS PROCESS

SEA21 uses planning tools to estimate the duration required to complete a ship availabilities. The Availability Duration Scorecard (ADS) uses known maintenance and modernization requirements to calculate the required length of time to execute a ship's CNO availability. The ADS takes information from the Navy Data Environment (NDE), Participating Acquisition Resource Manager (PARM) fielding plans, deferred maintenance, and Continuous Monitoring Program (CMP) tasks are included in duration projections (SEA21 2021).

The legacy Duration Methodology incorporated the Current Ship's Maintenance Project (CSMP), Tanks and Voids (T&V), modernization efforts, and notional assumptions (SEA21 2021). It did not include the complexity of maintenance activities, impacts of previous availability shifts, or the age of the ship. The equation only accounts for the start of an availability, the time the ship is docked, and the service restoration. See Figure 2.

Surface Maintenance Engineering Planning Program (SURFMEPP) is an entity of NAVSEA that serves to support ship readiness (Figure 1). This group manages Surface Ship Class Maintenance Plans and prepares ship sheets that define resources required to support CNO availabilities. Stakeholders (TYCOM, CNRMC, RMC and PE) continuously provide feedback to assist with availability maintenance planning (SEA21 2021).

The Duration Analysis Process requires information from several data sources:

1. Navy Data Environment – This is a centralized database used to manage Navy modernization, maintenance, logistics, workload and performance.
2. PARM Fielding Plans – This documents the material required to execute their individual alterations if those alterations are not part of the major ship class modernization program.
3. Deferred maintenance items and CSMP.
4. Previously executed availability/alteration historical data.
5. Technical Foundation Papers.
6. OPNAV LTR 4700, which provides the notional durations and maintenance cycles and repair days for depot level maintenance.
7. Tank Planning Reports and models.

Using the data provided, the analysis includes the following:

1. Alterations – Determine if the ship is first in its ship class, whether the duration and testing have potential impacts to availability, or Forward Deployed Naval Forces (FDNF). Forward deployed ships tend to have prolonged operations with limited maintenance, and may not be able to return for regularly scheduled availabilities.
2. Maintenance tasks – Review SURFMEPP maintenance packages that include deferred maintenance and review docking requirements.

Upon completion of reviewing the data sources and conducting the analysis, the results produce a recommended availability duration. The duration estimate has room for availability schedule adjustments and mitigation strategies. The analysis also identifies any high-risk availabilities based on inputs to the availability work package. Other feedback may identify additional alterations and maintenance items needing to be corrected from these results.

This additional feedback was added to the Legacy ADS, which then became the Approved ADS, as shown in Figure 2.

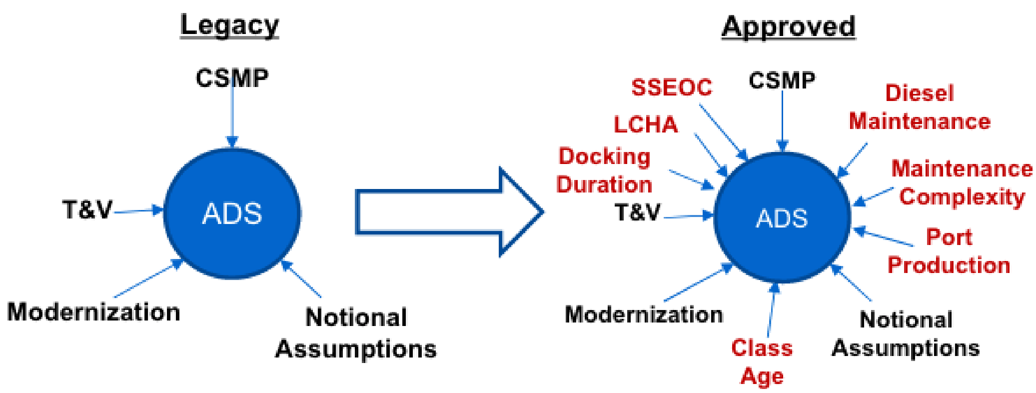


Figure 2. Legacy versus Approved Duration methodology. Source: SEA21 (2021).

The ADS process begins at the start of the availability planning (up to 700 days early) and is updated quarterly based on feedback from the stakeholders (SWRMC n.d.b)

The Duration Scorecard displays the following criteria:

1. The top of the scorecard identifies the ship name, hull number, fiscal year of when the availability will begin, the type of availability, and availability dates approved in the NDE database.

2. Take Aways (right side of the ADS) lists the planning status mismatches, pending/proposed availability changes, package lock milestones, and action items. The responsibilities are documented in a separate tracker.

3. The lower right displays the Major Maintenance Items. This section is populated by SURFMEPP with feedback from all the stakeholders, which include TYCOM, CNRMC, RMC, and Port Engineer (PE).

4. Major Ship Alterations lists major modernization alterations, installation, and test durations identified by a scheduling review.

5. Modernization Impact lists major assumptions, milestones, and sequences that may affect the schedule.

6. Certain Reporting Units will have Duration and Remarks listed in this section. The duration is shown in calendar days. Remarks will indicate any major shifts in schedule for the components listed (SEA21 2021).

Figure 3 shows an example of a duration scorecard used to plan a CNO availability. This scorecard is reviewed quarterly with inputs from all stakeholders. All stakeholders plan to 80% of the known solution on maintenance and modernization requirements received from NDE, PARM fielding plans, deferred maintenance, and CMP tasks. This process continues until the availability planning is locked at 100%. At this point, there are no additional inputs and the ADS is the duration estimate used to move forward with availability execution.

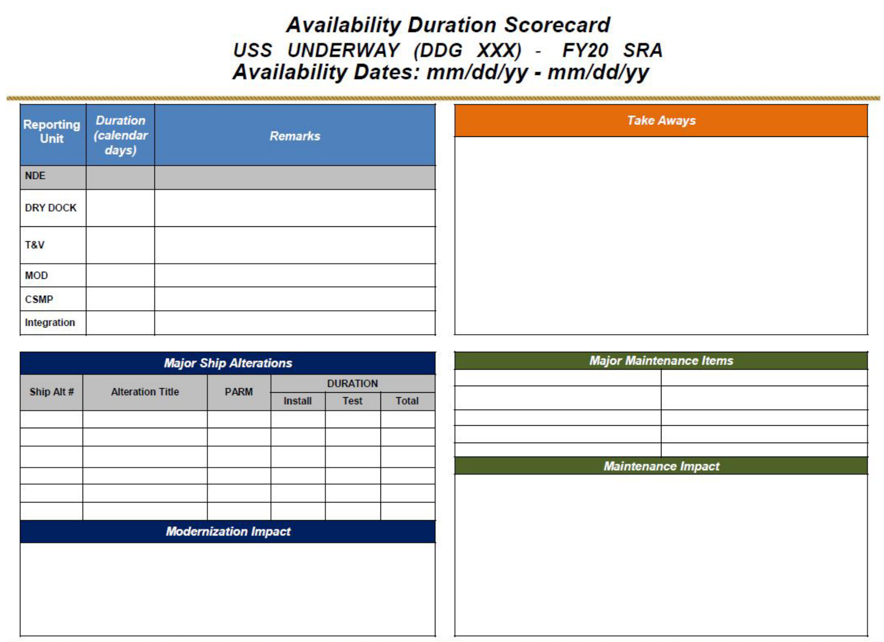


Figure 3. Availability Duration Scorecard example. Adapted from SEA21 (2021).

D. ANALYSIS OF ADS

Availability planners use a ship class template to plan the required timeline to conduct corrective or repair work during a CNO availability. The template is used to determine a notional schedule, uses data from the TFP, and edits are made to adjust for the required maintenance activities for that particular ship availability (Valdez 2022). Planners also review Total Ship Readiness Assessment (TSRA) reports. A TSRA is a scheduled event to provide a first inspection of the condition of a system. These events are scheduled in accordance to Technical Data Management Information System (TDMIS), a time-directed management system that tracks the life cycle of all systems.

Both TSRA and TDMIS drive the requirements to support initial ADS calculations. However, a TSRA report would not capture unplanned work. Delays can be attributed to lack of skilled workers, scheduling temporary services or the discovery of new work in the same space. This unplanned work will affect initial ADS calculations and can easily exceed initial estimates.

This thesis will determine if there is an accumulating effect from deferred (unplanned) maintenance that might not be observed with surface combatants. Continued maintenance deferrals will increase ship maintenance costs. There needs to be an understanding to budget for the high cost of deferral or have mitigations in place where the deferral is inevitable.

II. LITERATURE REVIEW

A. PREVIOUS RESEARCH

Caprio and Leszczynski (2012) used historical CNO availabilities to identify trends, similarities, and differences between on time and late availabilities. They also interviewed subject matter experts (SMEs) with years of shipyard experience and identified several factors that contributed to the late completion of CNO availabilities. These factors were:

1. Inadequate planning – At any given time, there are multiple availabilities executed at the shipyard. Each availability uses the same resources and personnel to support the work. Caprio and Leszczynski hypothesized that improper planning and utilizing inexperienced workers to complete the work contributes to schedule overrruns (2012).
2. New work – Each maintenance activity requires inspection prior to planning. However, problems appear during the execution phase and unexpected new work is identified. Unplanned work adds to the initial work plan and results in schedule overruns (Caprio and Leszczynski 2012). It is difficult to identify how the new work items will change the work scope and impact the initial schedule of work (Caprio and Leszczynski 2012).
3. Excessive over time – Unplanned work creates work delays. Work must be executed at a later timeframe, which requires additional coordination to determine if the new work will affect the spaces around it. As a project continues to run behind schedule to accommodate for changes, there may be an increase of overtime to rush work completion to meet schedule requirements (Caprio and Leszczynski 2012).
4. Work stoppage – Lack of personnel, resources or unplanned work have an impact on execution since those tasks are located on the critical path of a project. A critical path is the longest path to conduct a sequence of

> activities to complete a project. A delay in one activity will shift the schedule and affect the timeline for project completion. The discovery of a hidden deficiency can delay planned activities and will shift the schedule. Multiple instances on the critical path will result in delay to the availability end date (Caprio and Leszczynski 2012).

These factors are not accounted for with the ADS calculations. Since CNO planning begins up to 700 days ahead of the availability start, ADS uses historical data to conduct duration analysis to determine their values. The ADS calculations capture the labor and costs for planned work. Once the availability work begins, unplanned/unexpected work can arise and ADS is not re-evaluated after the availability schedule has been released for contract bid.

White also conducted an analysis of CNO availability performance metrics and their relationship to availability performance and based his research on Caprio and Leszczynski's findings (2013). Both theses evaluated similar data and found an association with hull type, the frequency of work stoppages, and trends that lead to increased costs for late availabilities (Caprio and Leszczynski, page v).

The data used in White's thesis consisted of submarine, aircraft-carrier, and surface ship CNO availabilities. Evaluating data early in planning stages can identify trends that can assist with better estimates for on time completion of an availability. The results of his analysis determined that certain performance metrics improved over a defined lean initiative period and may have contributed to availability completion (White 2013). White also noted the number of late days does not account for the size of the availability it represents (2013).

B. HOW CNO AVAILABILITIES ARE PLANNED

All ship availabilities are planned using the *Joint Fleet Maintenance Manual* (DON 2021). The JFMM provides a standardized set of requirements for all Type Commanders and subordinate commands. The manual provides guidance to ensure maintenance requirements are scheduled, completed, and documented for all Fleet commands (DON 2021). These standards are a way to enforce Regional Maintenance policies across all platforms. The development of this manual required tremendous efforts to standardize work practices, integrate accepted Regional Maintenance philosophies and offers the flexibility to allow for future changes in new Regional Maintenance policies (DON 2021).

Southwest Regional Maintenance Center (SWRMC) is a field activity under the Navy Regional Maintenance Center. SWRMC supports the NAVSEA mission to "design, build, deliver, and maintain ships and systems on time and on cost for the United States Navy" (SWRMC 2022). With the use of the JFMM, they support this maintenance philosophy by providing services to plan, execute, and close out maintenance actions. They accomplish this by providing D-level and I-level maintenance support for surface ships, submarines, and shore activities for the U.S. Pacific Fleet (SWRMC 2022). Their objective is to determine the manning necessary to support the requirements throughout the duration of the ship availability.

SWRMC maintenance planners coordinate the maintenance requirements for surface combatants. The type of availability also determines what type of work can be accomplished during the scheduled period. For example, a docking availability (i.e., DSRA, EDSRA) will focus on Hull, Maintenance & Equipment (HM&E) activities. Structural work consists of tasks performed on the shaft, hull preservation, painting, underwater work and/or tank blasting and coating. The maintenance planners also make the decision on whether certain types of maintenance will have to defer for the next maintenance availability.

Surface ships must meet certain planning milestones before execution of their CNO availability. Figure 4 shows the CNO availability planning process. CNO availability planning begins with the maintenance team and their review of the CSMP to ensure all ship deferred maintenance actions are documented. Next, SURFMEPP updates the Baseline Availability Work Package (BAWP) with new requirements. TYCOM, the Industrial Activity and Maintenance Team coordinate necessary pre-availability tests to verify the condition of equipment. A pre-availability test identifies required work to decrease the risk of equipment failures which could affect execution of testing and possible delays to availability execution. These results are submitted to the work package definition conference. TYCOM and the Industrial Activity issue the Pre-Availability Test and Inspection Report. The ship is then responsible to order the material to support the upcoming work. The ship must also cancel any outstanding Casualty Reports (CASREP) if those tasks are scheduled to be corrected during the scheduled ship availability. The final milestone is the arrival conference (DON 2021).

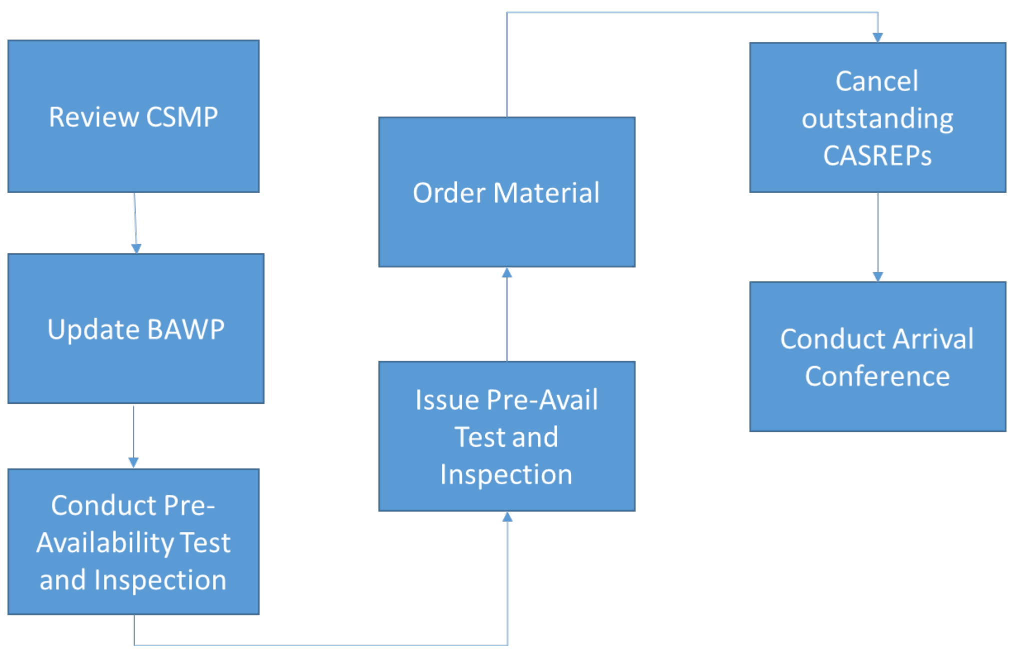


Figure 4. Typical CNO availability planning milestones (surface ships only). Source: DON (2021).

Availability planners also submit the Availability Work Package (AWP). The AWP is created after the completion of pre-availability test events and consists of all major maintenance actions (including Planned Maintenance System (PMS) generated maintenance actions known as work items or jobs), repairs, and ship alterations identified by ship's force and maintenance planners during pre-availability testing events (DON 2021). Finding major maintenance actions early helps identify critical path jobs that can directly affect the availability finish date. Any critical maintenance action that runs over its projected schedule will delay the overall availability completion date.

C. PLANNING FOR TANKS AND VOIDS

Tanks and Voids (T&V) are a component of the ADS. They are an important repair item on any USN ship because they present significant corrosion challenges. Corrosion in a tank or void can deplete the oxygen content of the air in a compartment (DON 2015).

Tanks hold various liquids such as fuel, water, waste, and oil. Voids are isolated and unused spaces that do not carry ballast or cargo (Maritime Good n.d.). Both tanks and voids are normally located below the water line of the ship but can also be near the main deck. Continued maintenance on T&V is critical since these structures hold vital elements to support the ship's mission and sustainment. When the ship is at sea, it is difficult to perform a thorough inspection. T&V are often located in confined spaces of irregular shapes in a maze of structural steel. A more accurate inspection can take place when the ship returns to port. When tank work begins, there could be more structural damage, severe corrosion, paint coating failure, cracks in the plating or bad welds discovered. These tank conditions are documented with the Navy Data Environment (NDE) database (SEA21 2021). Availability planners reference NDE to determine the condition of each T&V and set the maintenance requirements for availability planning.

Tank and void durations are developed using an algorithm that incorporates multiple parameters. Algorithms perform most accurately with ample and organized data. The data goes through test models to assure performance accuracy. The parameters for the performance of the algorithm include: the number of T&V, the size of each T&V, the coating condition of the tanks, and a margin of error based on the coating condition. The condition rating is a rust grade determined by the American Society for Testing and Materials (ASTM), corresponding to the percentage of the tank surface that is corroded. Each tank deteriorates at varying rates often depending on the location in the ship. For example, the top of the tank corrodes differently than the bottom of the tank. Coatings can corrode sooner on stiffening elements near the edges and the welds associated with them (DON 2015).

During the start of an availability, the tank is emptied and opened for the first inspection. The first inspection can reveal additional corrosion, defective welds, failed coatings, deformations and/or cracks incurred as the result of deferred maintenance and requiring additional corrosion abatement, weld repairs, and structural repair (Valdez 2022). The inspection can contribute to the need for additional structural repairs, weld repairs, and corrosion abatement.

Tanks are given a condition score based on analysis of the images collected. The coating conditions are evaluated for the overhead, bulkhead/shell, stiffener, and deck/bilge. See Table 1 for condition values (DON 2015).

Table 1. Coating condition values for tanks. Source: DON (2015).

Rating	Percentage of visible surface
P0	No value
P1	0% to 0.03%
P2	> 0.3% to 1%
P3	>1% to 10%
P4	>10%

The P# is assigned to all coating condition deficiencies. The deficiencies impact structural integrity and will require structural repairs for the associated coating system. They include the number of units, the size, and coating condition of the tanks in the package along with a margin of error. P1-P3 values will increase replacement costs to account for man-days per square foot. Values assigned with a P4 coating will increase man-days per square foot and will increase the cost to perform the structural work (SEA21 2021). The increase of man-days will lead to the addition of calendar-days to complete the scheduled task.

D. FLAWS WITH ADS ESTIMATES ON T&V

The addition of unplanned work will result in delays to the maintenance activity schedule, which affects both man-days and calendar-days. Man-days define how long an activity takes to complete and calendar-days indicates the elapsed time. The new work will be entered into the standard template along with the number of man-days required to complete the activity. The inconsistency lies in the misinterpretation of man-days calculated without including calendar-days for the new maintenance activity schedule. An activity may only take two days to complete but may have an elapsed period of two weeks on the schedule.

A work package describes the detailed actions required to complete the availability. The following are listed for each activity:

1. Activity ID – The identification number associated with the work scheduled.
2. Activity Description – Explains the type of work to be accomplished for the Activity ID.
3. Duration – The expected number of calendar days to complete the activity.
4. Early Start – The first possible day the activity can begin.
5. Early Finish – The first possible day the activity can be completed.
6. Late Start – The last possible day the activity can begin and still stay within the duration of the scheduled activity.
7. Late Finish – The last possible day the activity can finish and still stay within the duration of the scheduled activity.
8. Total Float – The total number of days that the contractor can delay a work activity without an impact to the schedule (DON 2004).

9. Predecessor – This identifies the previous Activity ID that must take place before execution of the current Activity ID.

10. Successor – This identifies the next Activity ID.

Figure 5 shows the scheduled activity ID of 12311003.06, which is the sixth fuel/ ballast tank identified for this ship availability. This Activity ID identified 19 activities requires for this fuel/ballast tank (12311003.06.01 through 12311003.06.19). Each activity description must be completed in sequential order and the first activity description can start as early as 7 July 2020. With an early start date of 7 July 2020 and an early finish date of 25 February 2021, this Activity ID (12311003.06) can be completed in 161 calendar-days. This duration includes elapsed time due to other work in the same compartment.

Activity ID	Activity Desc.	Dur	Early Start	Early Finish	Late Start	Late Finish	Total Float	Predecessors	Successor
12311003.06	FUEL / BALLAST TANK	161d	7-Jul-20	25-Feb-21	20-Jul-20	3-Mar-21	4d		
12311003.06.01	Submit Sandhole Sketch Layout	5d	7-Jul-20	13-Jul-20	20-Jul-20	24-Jul-20	9d	12310001.021.02	12311003.06.02
12311003.06.02	Cut Sandhole	5d	14-Jul-20	20-Jul-20	27-Jul-20	31-Jul-20	9d	12311003.06.01;12	12311003.06.03
12311003.06.03	Install Staging/Protective Containment	5d	21-Jul-20	27-Jul-20	3-Aug-20	7-Aug-20	9d	12311003.06.02	12311003.06.04
12311003.06.04	Remove Existing Zinc Anodes	3d	28-Jul-20	30-Jul-20	10-Aug-20	12-Aug-20	9d	12311003.06.03	12310001.021.05
12311003.06.05	Commercial Blast Tank (SSPC-SP-6)	8d	4-Aug-20	13-Aug-20	30-Oct-20	11-Nov-20	63d	12311006.15.01;12	12311006.15.02
12311003.06.06	Remove Defective Studs (as Directed)	2d	14-Aug-20	17-Aug-20	17-Dec-20	21-Dec-20	87d	12311003.06.05	12311003.06.07
12311003.06.07	Install New Manhole Cover Studs (Missing/Broken)	3d	18-Aug-20	20-Aug-20	21-Dec-20	28-Dec-20	87d	12311003.06.06	12311003.06.08
12311003.06.08	Surface Preparation Tank	2d	9-Sep-20	10-Sep-20	28-Dec-20	30-Dec-20	75d	12311006.15.06;12	12311003.06.09
12311003.06.09	Final Coat Tank	14d	11-Sep-20	30-Sep-20	30-Dec-20	21-Jan-21	75d	12311003.06.08	12311003.06.10
12311003.06.10	Install Sandhole Access	10d	15-Jan-21	29-Jan-21	21-Jan-21	4-Feb-21	4d	63131001.09.08;12	12311003.06.11
12311003.06.11	Air Test Weld Seams Sandhole Access	2d	1-Feb-21	2-Feb-21	4-Feb-21	8-Feb-21	4d	12311003.06.10	12311003.06.12
12311003.06.12	Nondestructive Testing Sandhole Access	2d	3-Feb-21	4-Feb-21	8-Feb-21	10-Feb-21	4d	12311003.06.11	12311003.06.13
12311003.06.13	Remove Staging/Protective Containment	3d	5-Feb-21	9-Feb-21	10-Feb-21	15-Feb-21	4d	12311003.06.12	12311003.06.14
12311003.06.14	Visual Inspection New Zincs / Submit Report	1d	10-Feb-21	10-Feb-21	15-Feb-21	16-Feb-21	4d	12311003.06.13	12311003.06.15
12311003.06.15	Install New Zincs	3d	11-Feb-21	15-Feb-21	16-Feb-21	19-Feb-21	4d	12311003.06.14	12311003.06.16
12311003.06.16	Torque Test	2d	16-Feb-21	17-Feb-21	19-Feb-21	23-Feb-21	4d	12311003.06.15	12311003.06.17
12311003.06.17	Resistance Test Zincs	2d	18-Feb-21	19-Feb-21	23-Feb-21	25-Feb-21	4d	12311003.06.16	12311003.06.18
12311003.06.18	Paint Touch Up	2d	22-Feb-21	23-Feb-21	25-Feb-21	1-Mar-21	4d	12311003.06.17	12311003.06.19
12311003.06.19	Completion Air Test	2d	24-Feb-21	25-Feb-21	1-Mar-21	3-Mar-21	4d	12311003.06.18	12310001.021.12

Figure 5. Scheduled activity for a fuel/ballast tank. Source: Valdez (2022).

Fuel/ballast tank #6 identified six additional activities (12311003.06.14A through 12311003.06.14E) that required a Request for Contract Change (RCC). An RCC needs to be authorized for the costs associated with the growth work. The six RCCs added an additional 14 man-days to complete the activities but the entire duration time increased from 161 calendar-days (Figure 5) to 206 calendar-days (Figure 6). There is a 45 calendar-day difference to complete the additional RCCs since the Activity IDs could not be completed in sequence. The previously scheduled tasks did not provide time to include the addition of new work. This can be shown with Activity ID 12311003.06.14A (RCC 534) with the removal and disposal of systems fluids and the completion of the RCC with Activity ID 12311003.06.14E with paint touch up. This is one example of how availability planners view delays in calendar-days.

Activity ID	Activity Desc.	Dur	Planned Start	Planned Finsh	Early Start	Early Finish
12311003.06	FUEL / BALLAST TANK	206d	8/26/2020	5/4/2021	8/26/2020	6/18/2021
12311003.06.01	Submit Sandhole Sketch Layout	5d	8/26/2020	8/27/2020	8/26/2020	8/27/2020
12311003.06.02	Cut Sandhole	5d	10/6/2020	10/6/2020	10/6/2020	10/6/2020
12311003.06.03	Install Staging/Protective Containment	5d	9/24/2020	9/25/2020	9/24/2020	9/25/2020
12311003.06.04	(IDR 0589 20% Exception) Remove Existing Zinc Anodes / Inspect Submit Report	3d	9/24/2020	9/25/2020	9/24/2020	9/25/2020
12311003.06.05	Commercial Blast Tank (SSPC-SP-6)	8d	9/30/2020	10/7/2020	9/30/2020	10/7/2020
12311003.06.08	Surface Preparation Tank	2d	10/6/2020	10/7/2020	10/6/2020	10/7/2020
12311003.06.09	Final Coat Tank	14d	10/6/2020	10/13/2020	10/6/2020	10/13/2020
12311003.06.10	Install Sandhole Access	10d	11/4/2020	12/7/2020	11/4/2020	12/7/2020
12311003.06.11	Air Test Weld Seams Sandhole Access	2d	12/14/2020	12/15/2020	12/14/2020	12/15/2020
12311003.06.12	Nondestructive Testing Sandhole Access	2d	12/14/2020	12/15/2020	12/14/2020	12/15/2020
12311003.06.13	Remove Staging/Protective Containment	3d	11/10/2020	12/8/2020	11/10/2020	12/8/2020
12311003.06.14	Visual Inspection New Zincs / Submit Report	1d	1/22/2021	1/22/2021	1/22/2021	1/22/2021
12311003.06.14A	RCC 534 Remove & Dispose of Systems Fluids	2d	3/26/2021	3/29/2021	4/19/2021	4/23/2021
12311003.06.14B	RCC 534 Remove Piping	2d	3/30/2021	3/31/2021	4/2/2021	5/14/2021
12311003.06.14C	RCC 534 Install Piping	5d	4/1/2021	4/7/2021	4/9/2021	5/24/2021
12311003.06.14D	RCC 534 Accomplish Cleaning & Flushing	2d	4/8/2021	4/9/2021	4/23/2021	6/18/2021
12311003.06.14E	RCC 534 Accomplish 009-71	2d	4/8/2021	4/9/2021	6/4/2021	6/18/2021
12311003.06.14F	Remove Defective Studs (as Directed)	2d	4/12/2021	4/13/2021	4/2/2021	4/2/2021
12311003.06.14G	Install New Manhole Cover Studs (Missing/Broken)	3d	4/14/2021	4/16/2021	4/2/2021	4/30/2021
12311003.06.15	Install New Zincs	3d	1/22/2021	4/21/2021	1/22/2021	4/30/2021
12311003.06.16	Torque Test	2d	4/22/2021	4/23/2021	5/14/2021	5/14/2021
12311003.06.17	Resistance Test Zincs	2d	4/26/2021	4/27/2021	5/14/2021	5/14/2021
12311003.06.17A	RCC 534 Paint Touch up	1d	4/28/2021	4/28/2021	5/7/2021	5/7/2021
12311003.06.18	Paint Touch Up	2d	4/29/2021	4/30/2021	5/7/2021	5/7/2021
12311003.06.19	Completion Air Test (CFR 2846)	2d	5/3/2021	5/4/2021	5/17/2021	5/21/2021

Figure 6. Additional RCC affects total duration. Source: Valdez (2022).

Availability planners determine how RCCs affect the duration of a planned maintenance activity. This knowledge can be used as lessons learned and applied to future availability planning. However, ADS does not perform a post analysis after the scorecard is finalized. Without follow up, it is difficult to capture previous ship data execution and apply this knowledge for future availability planning.

E. FLAWS IN ADS FOR T&V

The effects of deferred work, growth work, and new work can affect the ADS calculations. Deferred work is a task that is postponed for a later time to complete. Deferred work causes: constrained schedules, budget limitations, inaccessible access, other maintenance taking priority, and insufficient workforce to support the work. Growth work is discovered after the start of an availability. An example of growth work is the initial action to test a pump and then find it needs repair by replacing the gasket and bearings. New work is an effort not in the original work package. The addition of a new pump would require adjustments to the budget and schedule because it was not part of the initial planning.

The identification of growth work requires modifications to the schedules. This requires adjustments to the timeline to perform the work and determine if it affects any corresponding maintenance actions that are ongoing in the same space. ADS plans for repair work found in CSMP and only calculates labor and costs for potential growth work. The growth work estimates do not include factors related to execution, such as waiting on materials, reassignment of work crew, or waiting on temporary services. The inaccurate scope of growth work will produce a domino effect for the scheduled timeline and ultimately delay the original schedule.

III. CNO AVAILABILITY ESTIMATION ON TANKS AND VOIDS

A. INTRODUCTION

This chapter examines ship availabilities and the obstacles created from various elements that delay the process of completing maintenance activities. The tables illustrate examples of tank activities and whether certain factors create a delay between an estimated timeline versus actual execution. Evaluation also includes newly discovered repairs and where the square footage of the tanks contributes to additional delays. Through regression analysis, the chapter evaluates the time differential between various ships and highlights factors that are created during the availability execution. These factors could potentially be included in the ADS calculation to better estimate the availability duration.

B. ADS PLANNING FOR TANKS AND VOIDS

Each type of ship has a known number of tanks and square footage to use for duration estimates. Maintenance planners use schedule templates and historical data to plan a timeline to execute the next maintenance availability. They use a class maintenance plan to direct work and the maintenance requirements on when to perform the work. Duration estimates also depend on site inspections performed prior to the start of an availability.

Figure 5 lists the maintenance activities for a fuel/ballast tank, which is an excerpt of an availability schedule. Availability planners determine the minimum timelines to execute each activity and adjust their values based on inspections and previous maintenance logs. Their inputs are used to help generate the necessary values to contribute to the ADS calculation for the ship availability duration. Availability planners also use previous ship availabilities to adjust for future planning (Valdez 2022). Work on T&V is a major contributor to a ship availability and is essential to plan the correct timeline to perform the required maintenance activities.

Availability planners use old data, predicted data, actual data, and close out data. The continual monitoring of a previous ship's availability can contribute to the planning of the next ship availability. When work begins, the ship may encounter growth and new work. Growth work is identified during the open and inspect phase. This creates "work package churn," which creates new work required to execute. These additions may exceed the ADS estimates provided during the planning phases.

ADS captures the minimal duration required to move forward with an availability by calculating labor and cost data to perform the defined maintenance actions. It does not capture new work identified during initial inspections. In a previous scenario, the ADS calculations used an estimate from TYCOM for an SRA performed on the East Coast for a West Coast ship (Valdez 2022). The East Coast ship availability was planned for known maintenance repairs. However, the scope was not defined for the West Coast ship. The emphasis was on staying within a fixed budget and schedule, but the execution did not account for setup/breakdown for the fire watch and unknown factors for other repairs that would be needed for the West Coast ship. The ADS estimate did not include the proper preparations. A space must be setup properly, which includes the scheduling of temporary services (low pressure air, power, and lighting). Access cuts may be required to accommodate the space needed to perform the maintenance action. Proper planning details are needed in order to make an accurate estimate.

C. ANALYSIS OF ADS ESTIMATE VERSUS ACTUAL EXECUTION

This section presents several tables comparing ADS estimates to actual availability execution. The sample set includes cruisers, destroyers, and amphibious ships. Table 2 indicates that most ships exceed their ADS estimates and one ship exceeded its estimate by over 500 calendar-days. The delay was due to underestimating the amount of work required to bring that ship back online. USS *Cowpens* (CG 63) was the first ship to enter the Navy's Service Life Extension Program (SLEP) for USN cruisers. The program was intended to reduce maintenance costs and reduce risks by temporarily turning off the ship for three years. After this period, the ship would enter a modernization overhaul to further extend the life of the ship. The USS *Cowpens* (CG 63) availability had more work than anticipated to bring this ship to an operational status. This ship experienced significant changes to the original work packages and delays with material availability.

The USS *Mobile Bay* (CG 53) appears to have completed their availability earlier than expected with 109 calendar-days under the estimated time of 406 calendar-days.

However, the USS *Mobile Bay*'s availability type changed from a DSRA to an SRA. A DSRA requires the ship to dry-dock because the ship availability has maintenance actions that require extensive maintenance and modernization. When the availability scope changed to an SRA, the number of maintenance activities was reduced and the ship completed the SRA in 109 days less than what was estimated for the longer duration DSRA.

An example of how growth work affects the availability is observed with the USS *Decatur* (DDG 73). The ADS estimate was 493 calendar-days to complete the scheduled maintenance actions. During the execution of tank work, the maintenance crew discovered that various systems were contaminated and as a result the systems had to be flushed. This unexpected situation put the tank schedule behind schedule and greatly extended the availability by 238 calendar days.

Table 2. ADS vs. actual days executed (CG and DDG). Source: Valdez (2022)

Hull Number	Ship Name	Type of Availability	ADS calendar-days estimated	Actual maintenance calendar-days	Difference
CG 53	USS MOBILE BAY	SRA*	406	297	-109
CG 57	USS LAKE CHAMPLAIN	SRA	346	275	-71
CG 63	USS COWPENS	SRA	686	1264	578
DDG 60	USS PAUL HAMILTON	SRA	261	246	-15
DDG 63	USS STETHEM	DOCK	551	731	180
DDG 73	USS DECATUR	DOCK	493	731	238
DDG77	USS O'KANE	SRA	544	593	49
DDG 86	USS SHOUP	DOCK	506	728	222
DDG 104	USS STERETT	SRA	239	275	36
DDG 105	USS DEWEY	SRA	411	284	-127
DDG 106	USS STOCKDALE	SRA	254	173	-81
DDG 111	USS SPRUANCE	DOCK	253	267	14
DDG 113	USS JOHN FINN	SRA	149	183	34
*** Availability Type changed from DSRA to SRA**					

D. ANALYSIS OF ADS ESTIMATES FOR T&V DATA

This section performs a regression analysis to determine if any correlation exists between the size of the tanks, the number of maintenance actions, and whether growth work has any effect on the timeline to execute and complete the proposed maintenance activities.

Work on T&V requires input from the Current Ship's Maintenance Project (CSMP). The CSMP is a database that lists the deferred maintenance and the material condition of a ship (DON 2015). The CSMP provides maintenance managers a method to manage and control deferred maintenance, which assists with financial, operational, and analytical purposes. Using the CSMP identifies the deferred maintenance actions and the condition of the ship to assist with availability planning and ADS calculations (DON 2021). The CSMP is also used to determine any class wide maintenance problems and trends, which can be used to develop future maintenance budgets and scheduling of availabilities.

In addition to data from the CSMP and site inspections, RMC availability planners also use inputs from ship's force and previous availability execution to determine the timelines to perform the required maintenance. However, their calculations do not match up with ADS calculations. The objective is to determine if the number of maintenance actions or the number of RCCs contribute to delays in availability execution. Maintenance actions are defined by the activity description. The data summarizes the number of activities scheduled for each ship. An activity is a maintenance action scheduled for one tank, cofferdam or void and does not reflect the number of activities per tank, cofferdam or void.

Table 3 shows that every ship availability examined experienced a change in scope with the number of tank maintenance activities completed. For USS *Mobile Bay* (CG 53), 25 tanks required maintenance for this availability. The next column indicates the actual number of tank activities completed during that scheduled availability. This ship did not complete all scheduled maintenance activities since the work package required additional work on cofferdams and the ship experienced stability issues, which caused delays in executing the planned maintenance schedule. Over 45% of the initial packaged was de-scoped, which resulted in a lower number of tank activities completed for this ship.

For some hulls, the number of maintenance activities on tanks increased after ships began their availability. USS *Harpers Ferry* (LSD 49) originally had 529 tank maintenance activities planned for the availability. At the end of the availability, the ship completed 666 tank activities. This ship encountered growth work and had a limited labor force to complete the work.

Table 3. Tank and void actions. Source: Valdez (2022).

Hull Number	Ship Name	Total sq. ft. of tanks	Number of tank activities (planned)	Number of tank activities (completed)	Delta
CG 53	USS Mobile Bay	203,539	25	13	-12
CG 70	USS Lake Erie	211,458	77	131	54
DDG 60	USS Paul Hamilton	147,571	20	17	-3
DDG 73	USS Decatur	147,571	195	168	-27
DDG 106	USS Stockdale	142,289	51	48	-3
LHD 4	USS Boxer	1,109,249	298	145	-153
LHD 8	USS Makin Island	1,122,920	241	258	17
LSD 45	USS Comstock	499,490	572	655	83
LSD 47	USS Rushmore	498,033	601	593	-8
LSD 49	USS Harpers Ferry	487,460	529	666	137

Table 4 uses the same hulls listed in Table 3 and now includes the number of planned maintenance days and the number of actual maintenance days used to complete the tank activities. The last column titled Delta indicates the difference between the planner's estimates compared to the actual number of maintenance days recorded to complete the tank activities. A positive value indicates the ship availability exceeded the estimate, and a negative value indicates the availability completed in less time than planned. For this data set, USS *Paul Hamilton* (DDG 60) provides an inaccurate view on the days required to complete this ship availability. The original work package required the ship to empty three tank groups but due to stability issues, it could only perform work on two tank groups at a time. Therefore, the scope of USS *Paul Hamilton* (DDG 60) was reduced and resulted in a shorter availability. Since the ship could not complete the required tank actions, the work was deferred until its next availability. USS *Makin Island* (LHD 8) also appears to have required less days to complete her maintenance actions by 134 days. This ship also had her scope reduced because the availability duration could not accommodate all the ship alterations scheduled. The ship had to de-scope her availability by 60% because it had to exit the availability earlier to support an upcoming deployment. Consequently, no availability was done on time or before schedule.

Table 4. Tank and void maintenance days. Source: Valdez (2022).

Hull Number	Number of tanks	Total sq. ft. of tanks	Maintenance days (planned)	Maintenance days (actual)	Delta
CG 53	94	203,539	25	13	-12
CG 70	96	211,458	77	131	54
DDG 60	85	147,571	20	17	-3
DDG 73	85	147,571	195	168	-27
DDG 106	84	142,289	51	48	-3
LHD 4	168	1,109,249	298	145	-153
LHD 8	190	1,122,920	241	258	17
LSD 45	224	499,490	572	655	83
LSD 47	223	498,033	601	593	-8
LSD 49	227	487,460	529	666	137

Table 5 displays maintenance days estimated by planners compared to ADS estimates for the number of days to complete T&V activities. ADS used the same data as the availability planners but arrives at different values. This shows a discrepancy on how RMC availability planners and ADS arrive at their estimated timelines. A further analysis is required if the number and size of tanks affects maintenance execution.

Table 5. Planner estimates versus ADS. Source: Valdez (2022).

Hull Number	Ship Name	Maintenance calendar days for T&V (planners estimate)	Maintenance calendar days for T&V (ADS estimate)	Delta
CG 53	USS Mobile Bay	119	296	177
CG 70	USS Lake Erie	224	141	-83
DDG 60	USS Paul Hamilton	308	63	-245
DDG 73	USS Decatur	136	133	-3
DDG 106	USS Stockdale	71	49	-22
LHD 4	USS Boxer	206	250	44
LHD 8	USS Makin Island	355	326	-29
LSD 45	USS Comstock	425	512	87
LSD 47	USS Rushmore	147	249	102
LSD 49	USS Harpers Ferry	205	351	146

The updated scorecard is intended to provide better estimates to support planning of CNO availabilities. However, even with the updated ADS, CNO availability estimates are under-estimating the duration of availabilities and many ships continue to be late.

E. REASONS FOR INACCURATE CALCULATIONS

Based on the data presented, the following are reasons why T&V estimates are inaccurate:

1. Deployments.

   Ships that are forward deployed need to focus on more robust mission requirements and therefore are not able to maintain a normal maintenance schedule. Extended deployments also affect their timeline to return and conduct their maintenance availability requirements.

2. Age of the hull.

   The average age of a USN Cruiser is over 30 years old, the average USN Destroyer is around 26 years and the average landing ship dock amphibious ship is 31 years. The current fleet of surface combatants and amphibious ships are heavily used supporting longer deployments. The older platforms require more maintenance care and upkeep to maintain operations. There is no clear definition of aging and how it factors into the ADS duration. Using a standard value is not representative of each type of ship and the operations it has endured. With a fleet that continues to age, the factors of aging are not properly calculated in ADS.

3. Preparation work (setup/teardown).

The space needs to be prepared correctly before work on a tank begins. This may require the draining or disposal of fluids, access cuts or the arrangement of temporary services to support the work. Temporary services include lighting, low pressure air, or lighting. The timeline to make these preparations are not part of the ADS calculations.

4. Interferences/obstructions are not part of planning.

This includes material that prevents access to the tank and requires additional time to remove the obstruction. Examples are ladders, lockers, piping, wiring, and lighting. These are work stoppages that impact the maintenance activities and can create delays.

5. Level of knowledge.

Traditional methods of training ship’s force to operate and maintain complex systems are comprised of instructor-led classes with a combination of on-site, firsthand experience. Training today utilizes computer-based methods that do not impart the same level of knowledge or interaction with the sailor, especially in the areas of troubleshooting faults and corrosion abatement. As a result, maintenance previously performed by ship’s force is more often deferred to an outside entity via the CSMP. This vital onboard accumulation of the sailor/technician’s practical knowledge subsides because they no longer perform these tasks, which also produce an inaccurate scope of work needed for depot level repair and inhibits planners to accurately estimate anticipated labor and material cost. This level of knowledge loss is expanded as ship personnel turnover and pass on less and less knowledge to their replacements. The end result is an increased dependence on outside agencies (during availability periods) to perform repairs.

6. Unplanned work adds to schedule delays.

   The goal is to complete the AWP on time and according to the planned schedule. Unanticipated delays creates work stoppage that affects the schedule end date. These delays must be addressed before tank activities can resume back to its intended schedule.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. ANALYSIS RESULTS

A. INTRODUCTION

This chapter examines whether certain variables affect the duration of tank maintenance activities and the overall availability. Availability planners and ADS use the same data to plan each ship's availability duration, and the thesis analyzes which estimate is better. The analysis uses data for cruisers, destroyers and amphibious ships. These types of hulls are maintained in San Diego by private shipyards under contract to the RMC. For each ship analyzed, the data is provided before the start of the availability and after the availability was completed. Using completed data helps determine the accuracy of the estimates and can support planning for future availabilities. The data set includes ten (10) ship availabilities, each with tank activities and duration estimates presented in an Excel spreadsheet format. The thesis presents the final analysis in a series of graphs with an explanation of the regression analysis output.

The analysis uses availability planning sheets provided by RMC availability planners. Each planning sheet lists the maintenance activities for the entire ship, but filters the data to focus only on Activity IDs that begin with "123xxxxxx." The first three numbers indicate activities associated with tanks, voids, cofferdams, sumps, and chain lockers. Each activity ID identifies: the duration; planned start and end dates; early start and finish dates; and late start and late finish dates. Planning sheets were provided before the start and for the end of the availability. In this data set, nearly all of the hulls (8 out of 10) exited their availabilities late. Generally, we want more data for a regression analysis to discern any trends.

The thesis also analyzed the accuracy of the ADS estimates provided by the ADS Scorecards. The scorecards contain an estimate of the work duration days for tanks and voids, and those values were analyzed against the planning sheets.

B. TANKS AND VOIDS DATA SET DESCRIPTION

The independent variables include the number of tanks, total square footage of all tanks, number of tank activities planned, number of tank activities completed, the number of RCCs added to the work package, and the number of RCCs that were insignificant and deleted. As defined in Chapter II, an RCC describes new work added to the work package that was not originally planned. An RCC requires modification to the T&V timeline to complete the scheduled activities. Availability planners update the planning sheets to include the addition of the RCCs during the execution of the availability. The planners also identify the effects on the timeline to complete the originally scheduled tank activities. The dependent variables include the planned maintenance days to support T&V activities, the actual maintenance days for T&V activities, and the ADS estimate to support T&V activities. All days calculated are in calendar-days.

A regression analysis determines if there is a relationship between the independent variable(s) and the dependent variable(s). The graphical analysis shows an equation describing the mathematical relations and includes a coefficient and the R-squared value indicating how strong the linear relationship is between the variables.

The regression analysis generates several measures explaining how well the fitted equation fits the data. Here we describe the regression measures:

1. **Multiple R** is the correlation coefficient that describes how strong the correlation is between the independent and dependent variables. A higher value indicates a stronger relationship with the data analyzed.

2. **R square** is the coefficient of determination that indicates how strong the linear relationship is. Values range from 0 to 1. A low value indicates a poor fit for the data set.

3. **Adjusted R square** is the value used when there is more than one independent variable used in the model.

4. **Standard error** describes the precision of the coefficient measured (or how wrong the regression model is). Lower values indicate a smaller distance between the data points and a better fit for the model.

5. **Observations** is the number of ships used in this data analysis.

Table 6 lists the hulls used for this analysis. Each type of ship has a given number of tanks and square footage that needs routine maintenance. The analysis is based on the number of tank activities planned for that particular availability. Items designated with an asterisk (*) include the sum of all tanks, voids, cofferdams, chain lockers or sumps scheduled for that availability, which is greater than the total number of tanks.

Table 6. Tanks analyzed. Source: Valdez (2022).

Ship Hull	Ship Name	Number of tanks	Total Sq. Ft of tanks	Number of tank activities planned
CG 53	USS Mobile Bay	94	203,539	25
CG 70	USS Lake Erie	96	211,458	77
DDG 60	USS Paul Hamilton	85	147,571	20
DDG 73	USS Decatur	85	147,571	195*
DDG 106	USS Stockdale	84	142,289	51
LHD 4	USS Boxer	168	1,109,249	298*
LHD 8	USS Makin Island	190	1,122,920	241*
LSD 45	USS Comstock	224	499,490	572*
LSD 47	USS Rushmore	223	498,033	601*
LSD 49	USS Harpers Ferry	227	487,460	529*
*Activity planned either on a tank, cofferdam, void, chain locker, or sump. Tanks can also be separated out as different segments.				

Each ship availability planning sheet centers on activities pertaining to tanks, voids, and cofferdams. Planners determine which tanks require maintenance for that particular availability. Table 7 identifies the number of planned tank activities, the number of actual tank activities conducted, the number of RCCs added and deleted, and the total number of tank activities for each ship listed. Table 7 shows how the number of planned tank activities can easily evolve with the addition of new work and increase the eventual number of tank activities completed for that particular availability. For instance, the USS *Lake Erie* (CG 70) originally planned 77 tank activities before the start of the availability. During her availability, additional work on the 02 level disrupted the scheduled tank work and the disruptions caused stability issues. The disruptions increased the number of tank activities and required the addition of many RCCs to the work package. The final count of tank activities for USS *Lake Erie* (CG 70) was 193 items.

Table 7. Tank activities identified from planning sheets

Ship Hull	Tank Activities (planned)	Tank activities (actual)	Number of RCC added	Number of RCC deleted	Total Number of tank activities
CG 53	25	13	21	25	59
CG 70	77	131	29	33	193
DDG 60	20	17	0	0	17
DDG 73	195	168	16	45	229
DDG 106	51	48	3	5	56
LHD 4	298	145	13	0	158
LHD 8	241	258	167	41	466
LSD 45	572	655	64	16	735
LSD 47	601	593	10	9	612
LSD 49	529	666	57	88	811

Table 8 presents the number of planned maintenance days to complete the tank activities including: the planners' estimates, ADS estimates, and the actual maintenance days for the T&V activities. The last two columns show the difference between actual execution compared to the planners and ADS estimates, respectively. A negative (-) value indicates the estimate was low, and a positive (+) value indicates the estimate was high.

Table 8. Planners and ADS estimates for T&V maintenance

Ship Hull	Planners' estimate (days)	ADS estimate (days)	Actual maintenance days for T&V (days)	Difference between planners' estimate and actual	Difference between ADS estimate and actual
CG 53	119	296	172	-53	+124
CG 70	224	141	358	-134	-217
DDG 60	308	63	91	+217	-28
DDG 73	136	133	279	-143	-146
DDG 106	71	49	119	- 48	-70
LHD 4	206	250	399	-193	-149
LHD 8	355	326	221	-134	+105
LSD 45	425	512	453	-28	+59
LSD 47	147	249	423	-276	-174
LSD 49	205	351	328	-123	+23

C. ANALYSIS OF ESTIMATES AND THEIR ACCURACY

Figure 7 displays the planners' estimate of maintenance days versus the number of planned tank activities, and Table 9 shows the regression statistics for this model. There is no correlation between the planners' estimates and the planned number of tank activities. We expected a correlation between the number of maintenance days and the number of tank activities.

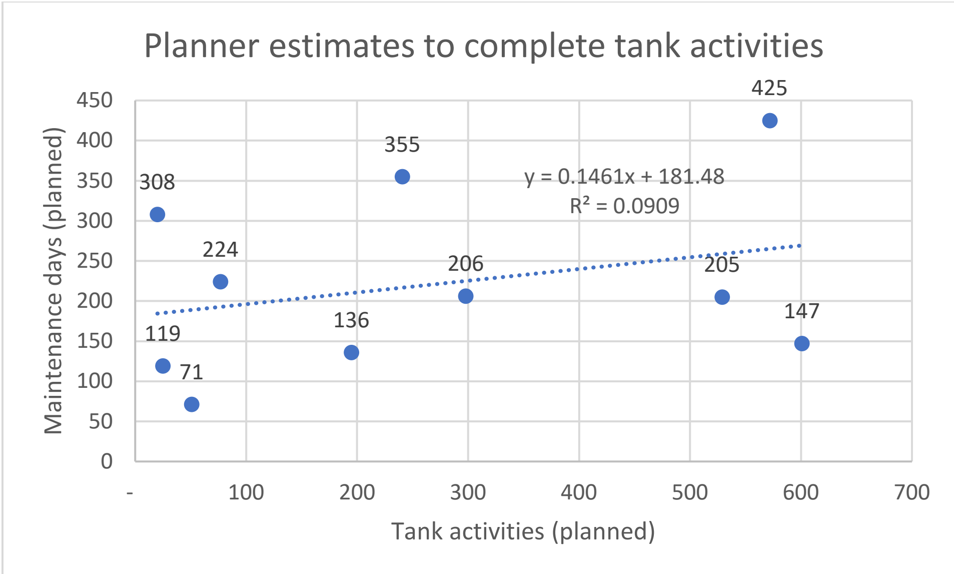


Figure 7. Planner estimates on number of days to complete tank activities

Table 9. Planner estimates for number of days required to complete tank activities

Regression Statistics	
Multiple R	0.301461988
R Square	0.09087933
Adjusted R Square	-0.022760753
Standard Error	113.428044
Observations	10

Figure 8 shows the ADS estimate in calendar-days to complete the planned maintenance activities. Figure 8 does not show a linear relationship between the ADS estimate and the number of planned tank activities. In Table 10, the R Square value of 0.4960 indicates this model accounts for about 49.6% of the dependent variable's variance. A high R Square value indicates how well the model fits the data. The higher R square value indicates ADS provided a better estimate based on the number of planned tank activities compared to the planners' R square value of 0.0908 found in Table 9. However, the Standard Error of 108.24 indicates how inaccurate the regression model is on average. Lower values are better since it indicates the distance between the data points and the fitted values are smaller. A large value indicates a further distance between each data point and may not be a true representation of how ADS estimates are more accurate for the number of days for the tank activities.

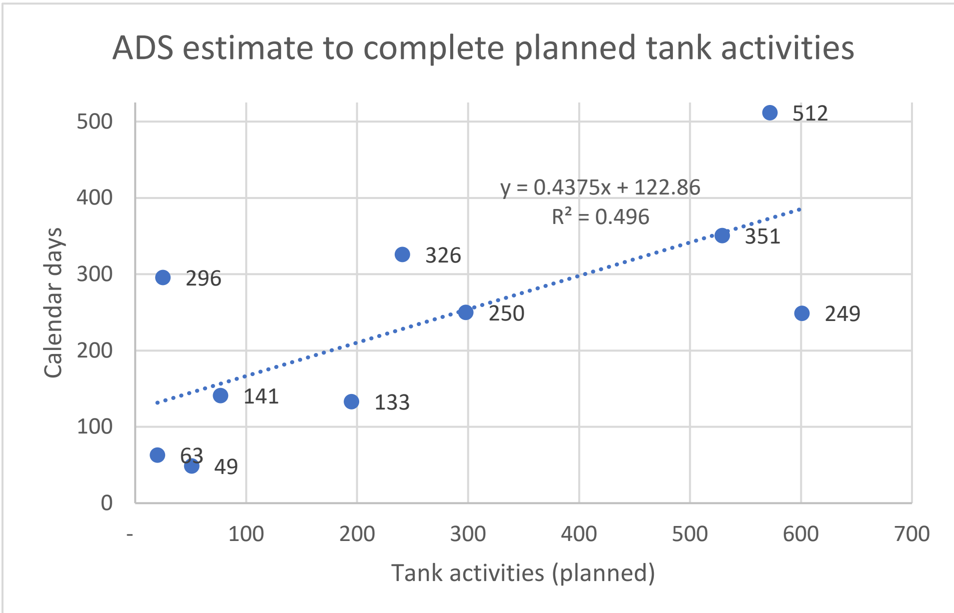


Figure 8. ADS estimate for number of tank activities planned

Table 10. Regression values for ADS estimates

Regression Statistics	
Multiple R	0.704303534
R Square	0.496043467
Adjusted R Square	0.433048901
Standard Error	108.2415514
Observations	10

Figure 9 displays the number of maintenance days versus the number of tank activities. Table 11 shows the regression statistics. The Multiple R value of 0.7372 indicates a correlation between the number of days to complete the tank activities and RCCs. For this data set, the standard error of 106.65 is considered high. The high standard error indicates the coefficient is not precise, and the high standard error occurred because some data points are far from the regression line.

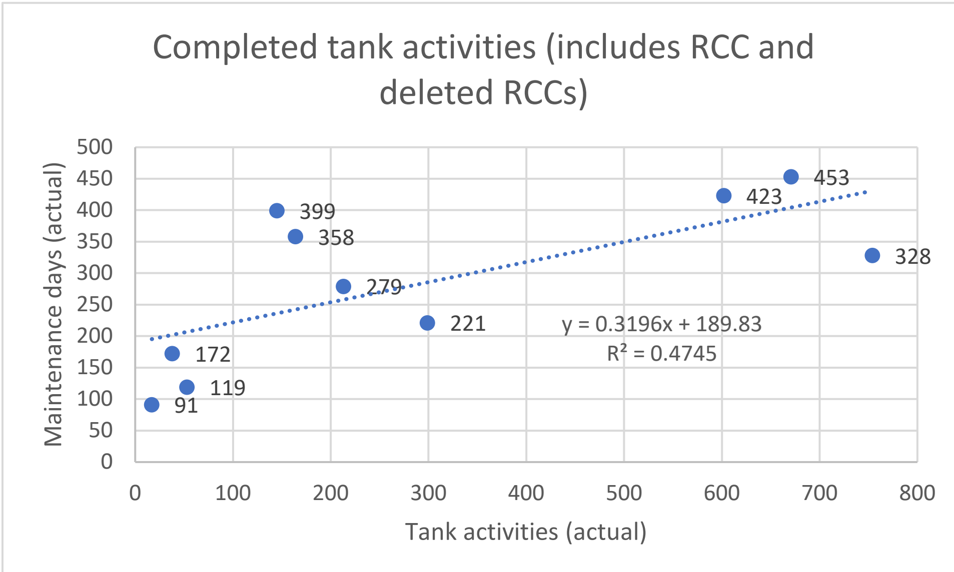


Figure 9. Completed tank activities that include RCCs and insignificant RCCs

Table 11. Regression statistics for actual maintenance days to complete tank activities (including RCCs)

Regression Statistics	
Multiple R	0.737284267
R Square	0.54358809
Adjusted R Square	0.315382135
Standard Error	106.6515499
Observations	10

Figure 10 displays the planner's estimates versus ADS estimates for the number of maintenance days to complete the tank activities. Table 12 shows the regression statistics. Both groups were provided the same information on what activities were required for that particular availability. The planners and ADS make similar estimates when the number of activities is low (~300 or less). Ships that planned more tank activities show a difference in estimates. The R Square value of 0.3094 is a low value. This indicates a poor fit for this data set and the estimates from the planners and ADS do not show a good linear relationship for the number of days required to support the tank activities.

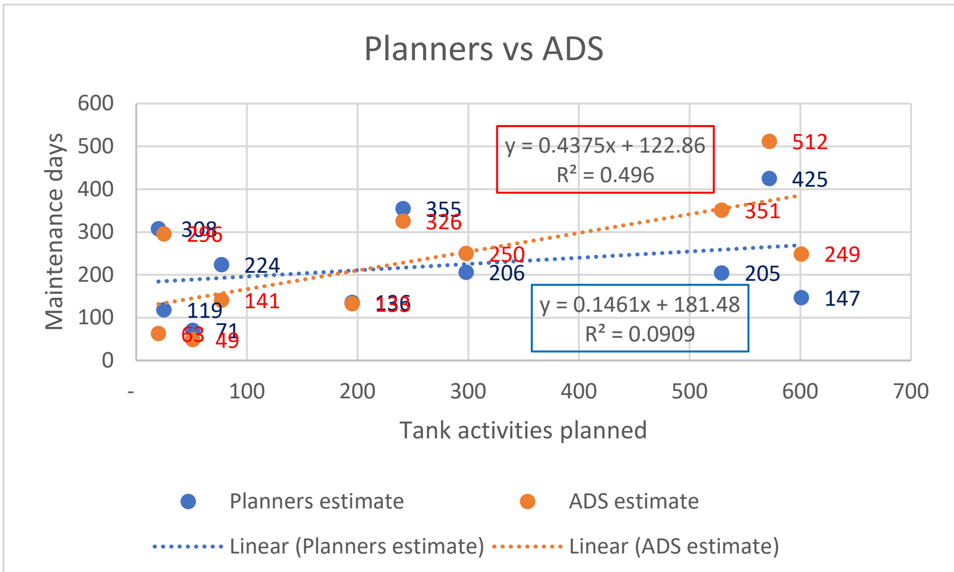


Figure 10. Planners versus ADS estimates for timeline to complete tank activities

Table 12. Regression values for Planners versus ADS estimates

Regression Statistics	
Multiple R	0.55623347
R Square	0.309395674
Adjusted R Square	0.223070133
Standard Error	126.7103574
Observations	10

D. POTENTIAL CAUSES FOR BAD CORRELATION

Each planning sheet identifies every maintenance activity for that particular ship availability. Each file includes anywhere from 12,000 to 17,000+ lines of activity descriptions. Even though the files followed similar layouts, there were differences in nomenclature that could cause confusion. Common data entry errors include inconsistent naming conventions and repeated descriptions that appear to be duplicates. Suspected duplicate entries were later verified as separate entries with their unique activity ID. Most activity descriptions indicated a ship location [example: accessible void (6-56-4-V)] and made it easy to determine which specific item was worked on. However, there were some data entries that indicated a component but did not provide a location (example: accessible void, preserve). This is easy to overlook and made it possible to not include that activity in the analysis.

The data set included a variety of hulls: two (2) cruisers, three (3) destroyers, and five (5) amphibious ships for a total of ten (10) data points. It is not a large data set, which makes it difficult to draw conclusions about planning availabilities. It is also not a consistent data set since certain hulls have over 30 years of service while some hulls only have 12–13 years of service. Older ships likely require more time for the same tank maintenance activity because they have endured more wear and tear. Even though there were limitations on the data set, it is puzzling to see how the same ship maintenance data requirements are interpreted differently. The only conclusion is the estimation process requires additional refinement to provide a better estimate.

V. CONCLUSION

A. SUMMARY

The Availability Duration Scorecard (ADS) is an estimation tool used to determine the duration of CNO availabilities. The current version of ADS (3.0) considers shipyard capacity and additional resources to improve ship availability duration estimates. It remains a tool to assist in availability planning and is not to be used as a contractual document (SEA 2021).

Previous studies suggested lateness was due to inadequate planning or underestimating growth work added to the work package. Some of the hulls analyzed had changes to their initial work packages, which inevitably delayed their exit from the maintenance availability. Such occurrences happen frequently and impact fleet readiness. The growth work also prevents proper planning to coordinate resources to support these efforts. Because planning can begin as soon as 700 days prior to the availability's start date, there is great potential for growth work to emerge in those 700 days, which may explain some of the inaccuracy of planning. Additionally, there are other factors to take into consideration. With older hulls, it is expected that complications will appear during the execution phase. Older hulls may carry equipment that is close to its end of service that may require replacement. Logistics support may be difficult due to parts obsolescence or unavailability. This results in substantial growth work to determine a suitable replacement. Growth work is not predictable, but using data from previous ship availabilities can help plan upcoming availabilities. But how does the Navy plan for growth work when work packages are locked before the start of an availability?

Availability planning requires accurate data. CSMP provides a record of maintenance requirements and includes details about deferred maintenance. Availability planners can refer to previous availability records to plan the most appropriate timelines to support upcoming maintenance requirements.

However, not all delays are due to planning shortfalls. The discovery of growth work contributes to unaccounted costs and schedule delays. Not all delays are due to planning. Delays can also be attributed to late contract awards, increase in scope, labor shortage, and delays in procuring material.

Several factors discovered during this research indicate the data was inconsistent. The availability planning sheets were not setup in the same format nor did they utilize a common nomenclature. As a result, the data provided leads to inconclusive decision making. The lack of standard terminology made it difficult to accurately determine the number of maintenance activities required for each availability. If there is not enough data, it creates a handicap to conduct an accurate duration estimate. The lack of data also makes it difficult to determine how ADS calculates the duration for T&V. This creates a level of inconclusiveness in this analysis of availability estimates. Without good data, it is difficult to measure the maintenance process and even more difficult to suggest improvements.

Many ships encountered deviations from their maintenance schedules. These situations are not properly reflected in the duration analysis and the deviations contribution to why the thesis was unable to find any correlations between the data. These ships experienced stability issues, contamination of tanks, labor issues, or early deployment.

The regression analysis did not show any significant relationships with the number of tanks, the number of planned maintenance activities, the addition of RCCs and the estimates provided by the availability planners and ADS. Logic suggests an increase in the number of tank actions requires more days to complete.

While ADS is not perfect, there needs to be post analysis conducted after the completion of an availability. ADS finalizes the scorecards before the start of an availability. There is no indication that the ADS is re-evaluated after the completion of an availability to determine if the estimates were correct. Planners conduct post analysis and use this final data to help plan for the next availability. It was necessary to use completed availability data to conduct a regression analysis on estimates from planners. The results were inconclusive since there was no clear indication on who provided better estimates.

The U.S. Navy plans to decommission 24 ships by the end of fiscal year 2023 (Eckstein 2022). This could increase current ship deployments, which may also delay scheduled availabilities. USS *Bonhomme Richard* (LHD 6) suffered a catastrophic fire in

July 2020. The cost to repair the ship was prohibitively expensive, so the ship was decommissioned. The Navy, with one less amphibious ship, will require other hulls in this ship class to extend their deployment and/or operational cycles. In order to fulfill the pre-existing USS *Bonhomme Richard* (LHD 6) commitments, other ships must adjust their maintenance timeline because now they cannot return for their regular scheduled availabilities. This will escalate costs from current levels.

While this thesis only analyzed tanks and voids, further research is needed to determine if additional components of the ADS may contribute to the overall delay of ship availability. Although components have been added to strengthen the ADS estimates, the missing component is the lack of data to accurately calculate the duration of each availability.

B. RECOMMENDATIONS

The intention of this analysis was to find correlations between known factors and the actual duration of maintenance for tanks and voids. However, the limited data set provided inadequate results. Data is necessary to identify trends and help create estimates that are more realistic. Further research requires a larger data set in order to conduct a proper regression analysis. A more comprehensive data set includes planning sheets for several hulls for each type of platform. Each type of ship supports multiple types of missions. It is possible that one class of ship, due to vigorous operational tempo, may have endured more wear and tear compared to another ship class. This could be the reason one class of ship may have taken longer to complete their maintenance requirement. By increasing the number of hulls, we can identify correlations between the various variables.

Another future area to explore is the size of the tanks. One suggestion is to group the ships by tank square footage. The tank square footage can be divided into three different levels: small (150k-400k), medium (400k-800k), and large (800k and higher). A previous observation in Table 8 indicated some ships had a small difference between duration estimates and actual days. These ships also had a smaller tank square footage. One assumption to analyze is if estimates are more accurate with a certain size of tanks. By using the same parameter (small, medium, or large), the analysis could determine how duration estimates may or may not vary. Setting this parameter would create a more accurate estimate with ADS.

The next area to address is the age of the fleet. The Navy is considering extending the service life of some ships, which could result in some ships being in service for over 50 years (Larter 2018). These ships will require more upkeep to maintain and typically encounter unexpected growth in work from the additional wear and tear. Adjustments are required for duration estimates to compensate. Any ships approaching a mid-life overhaul require different calculations for their duration estimate. These ships often have mid-service life projects that are complex in nature such as major alterations and installations that have been assigned well in advance of the event. Analyzing the age of the ship will help produce data to support the required maintenance calculations and create a more accurate duration analysis.

Good planning contributes to on-time delivery. We cannot plan for the unpredictable but we can predict the inevitable. We can use three known factors (hull type, tank square footage, and age) to identify possible gaps in duration estimates. These three improvements will aid in calculating a more accurate estimate. A more accurate estimate will lead to a more efficient ADS.

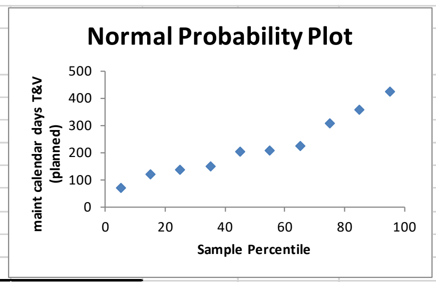
APPENDIX

A. REGRESSION ANALYTICS FOR PLANNER ESTIMATES TO COMPLETE TANK ACTIVITIES (FIGURE 7)

Figure 11 is the regression analytic report from Excel. All tables listed in this figure are derived from analyzing planner estimates for the number of planned tank activities. Since the data set only consists of 10 ships, the R square value of 0.0908 indicates no correlation between the number of tank activities and the days required to execute the planned tank activities.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.301461988
R Square	0.09087933
Adjusted R Square	-0.022760753
Standard Error	113.428044
Observations	10



ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	10289.03061	10289.03061	0.799711926	0.397284962
Residual	8	102927.3694	12865.92117		
Total	9	113216.4			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	181.4814403	55.70930916	3.257650166	0.011567881	53.01554296	309.9473376	53.01554296	309.9473376
# tanks activities (planned)	0.1461041	0.163378768	0.894266138	0.397284962	-0.230648015	0.522856215	-0.230648015	0.522856215

RESIDUAL OUTPUT

Observation	*Predicted maint calendar days T&V (planned)*	*Residuals*
1	185.1340428	-66.13404276
2	192.731456	31.26854403
3	184.4035223	123.5964777
4	209.9717398	-73.9717398
5	188.9327494	-117.9327494
6	225.0204621	-19.02046212
7	216.6925284	138.3074716
8	265.0529856	159.9470144
9	269.2900045	-122.2900045
10	258.7705093	-53.77050926

PROBABILITY OUTPUT

Percentile	*maint calendar days T&V (planned)*
5	71
15	119
25	136
35	147
45	205
55	206
65	224
75	308
85	355
95	425

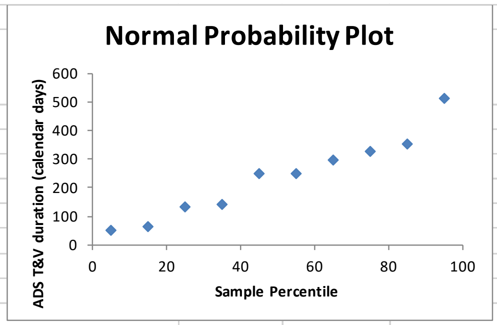
Figure 11. Regression report for Figure 7

B. REGRESSION ANALYTICS FOR ADS ESTIMATES FOR PLANNED TANK ACTIVITIES (FIGURE 8)

Figure 12 is the regression analytic report from Excel. All tables listed are derived from ADS estimates for the number of maintenance days required to support the planned tank activities. The R square value of 0.4960 indicates this model accounts for 49.6% of the dependent variable's variance. But a high value for the standard error (108.24) indicates the regression model is not very precise.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.704303534
R Square	0.496043467
Adjusted R Squar	0.433048901
Standard Error	108.2415514
Observations	10



ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	92258.13242	92258.13242	7.874384958	0.02297957
Residual	8	93729.86758	11716.23345		
Total	9	185988			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	122.8563955	53.16200329	2.3109813	0.049613026	0.264596042	245.4481949	0.264596042	245.4481949
# tanks activities (planned)	0.437499442	0.155908281	2.806133453	0.02297957	0.077974302	0.797024583	0.077974302	0.797024583

RESIDUAL OUTPUT

Observation	*duration (calendar days)*	*Residuals*
1	133.7938815	162.2061185
2	156.5438525	-15.54385254
3	131.6063843	-68.60638432
4	208.1687867	-75.16878674
5	145.168867	-96.16886703
6	253.2312293	-3.231229314
7	228.2937611	97.7062389
8	373.1060765	138.8939235
9	385.7935604	-136.7935604
10	354.2936005	-3.293600516

PROBABILITY OUTPUT

Percentile	*ADS T&V duration (calendar days)*
5	49
15	63
25	133
35	141
45	249
55	250
65	296
75	326
85	351
95	512

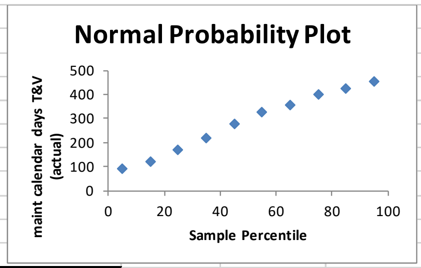
Figure 12. Regression report for Figure 8

C. REGRESSION ANALYTICS FOR COMPLETED TANK ACTIVITIES AND ALL RCC (FIGURE 9)

Figure 13 is the regression analytic report from Excel. All tables listed in this figure are derived from the analysis of completed tank activities, which includes the addition of RCCs added to the work package and the insignificant RCCs deleted. The Multiple R value of 0.7373 describes a strong correlation between the independent (all tank activities) and dependent (maintenance days). However, the standard error is high and indicates a low precision of the coefficient measured.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.737284267
R Square	0.54358809
Adjusted R Square	0.315382135
Standard Error	106.6515499
Observations	10



ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	81282.78142	27094.26047	2.382006594	0.168302509
Residual	6	68247.31858	11374.5531		
Total	9	149530.1			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	208.8996199	54.72890225	3.816989037	0.008791541	74.9828204	342.8164194	74.9828204	342.8164194
# tank activities (actual)	0.391632473	0.148622819	2.635076332	0.038795139	0.027965536	0.75529941	0.027965536	0.75529941
# RCC (tank) activities onto avail	-0.201074884	0.792548162	-0.253706833	0.80819207	-2.140370374	1.738220606	-2.140370374	1.738220606
# RCC (tank) activities with delete	-0.857426047	1.532206869	-0.559602012	0.596007043	-4.606601194	2.891749099	-4.606601194	2.891749099

RESIDUAL OUTPUT

Observation	*Predicted maint calendar days T&V (actual)*	*Residuals*
1	188.3326183	-16.33261831
2	226.0772426	131.9227574
3	215.557372	-124.557372
4	232.892505	46.10749496
5	222.8076237	-103.8076237
6	263.072355	135.927645
7	241.2068242	-20.20682423
8	438.8312801	14.16871986
9	431.4100929	-8.410092923
10	382.8120861	-54.81208612

PROBABILITY OUTPUT

Percentile	*maint calendar days T&V (actual)*
5	91
15	119
25	172
35	221
45	279
55	328
65	358
75	399
85	423
95	453

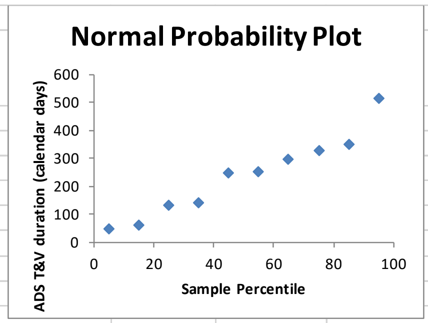
Figure 13. Regression report for Figure 9

D. REGRESSION ANALYTICS FOR PLANNERS AND ADS ESTIMATES (FIGURE 10)

Figure 14 is the regression analytic report from Excel. All tables listed are derived from planner estimates compared to ADS estimates. Both groups used the same information for each availability. The R square value of 0.3094 is a low value for both the planners and ADS. Both estimates do not indicate a strong linear relationship for the number of days requires to support the tank activities.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.55623347
R Square	0.309395674
Adjusted R Squar	0.223070133
Standard Error	126.7103574
Observations	10



ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	57543.88256	57543.88256	3.584057173	0.094962769
Residual	8	128444.1174	16055.51468		
Total	9	185988			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	80.44128589	91.89312326	0.875378734	0.406881334	-131.4646363	292.3472081	-131.4646363	292.3472081
maint calendar days T&V (planned)	0.712926749	0.376580168	1.893160631	0.094962769	-0.155468677	1.581322175	-0.155468677	1.581322175

RESIDUAL OUTPUT

Observation	*Predicted ADS T&V duration (calendar days)*	*Residuals*
1	165.279569	130.720431
2	240.1368777	-99.1368777
3	300.0227246	-237.0227246
4	177.3993238	-44.39932377
5	131.0590851	-82.05908508
6	227.3041962	22.69580379
7	333.5302818	-7.530281832
8	383.4351543	128.5648457
9	185.241518	63.75848199
10	226.5912695	124.4087305

PROBABILITY OUTPUT

Percentile	*ADS T&V duration (calendar days)*
5	49
15	63
25	133
35	141
45	249
55	250
65	296
75	326
85	351
95	512

Figure 14. Regression report for Figure 10

LIST OF REFERENCES

Button, Robert W., Bradley Martin, Jerry M. Sollinger, and Abraham Tidwell, 2015. “Assessment of Surface Ship Maintenance Requirements.” Santa Monica, CA: RAND Corporation, 2015. https://www.rand.org/pubs/research_reports/RR1155.html

Caprio, Joseph L. and Daniel Leszczynski. 2012. “A Preliminary Investigation into CNO Availability Schedule Overruns.” Master’s thesis, Naval Postgraduate School, Monterey, CA. https://calhoun.nps.edu/handle/10945/7315

Department of Defense. 2014. “Standard Practice: Reliability-Centered Maintenance (RCM) Process.” MIL-STD-3034, Revision A. Washington, DC: Department of Defense. http://everyspec.com/MIL-STD/MIL-STD-3000-9999/MIL-STD-3034A_50797/

Department of Navy. 2015a. Ship’s Maintenance and Material Management (3-M) Manuals. March 14, 2013. NAVSEAINST 4790.8C instruction.

———. 2015b. “Technical Manual for Corrosion Control Assessment and Maintenance Manual (CCAMM).” T9630-AB-MMD-010, Revision 3. Washington, D.C.: Naval Sea Systems Command.

———. 2021. “Joint Fleet Maintenance Manual (JFMM).” COMUSFLTFORMCOM 4790.3 Revision D Change 1. Instruction. Portsmouth, NH.

Donnelly, John M. 2020. “Costs Rise more than $100B to maintain Navy ships with clogging toilets and other issues.” Roll Call. Last modified March 25, 2020. https://www.rollcall.com/2020/03/25/warship-upkeep-cost-estimates-rise-100-billion-plus/

Eckstein, Megan. 2020a. “Navy Striving for 71% On-Time Ship Maintenance This Year, No Extensions by End of 2021.” USNI News. Last modified January 23, 2020. https://news.usni.org/2020/01/23/navy-striving-for-71-on-time-ship-maintenance-this-year-no-extensions-by-end-of-2021

———. 2020b. “NAVSEA: Analysis of Ship Repair Processes Led to Better On-Time Rates, More Realist Schedules.” USNI News. Last modified October 13, 2020. https://news.usni.org/2020/10/13/navsea-analysis-of-ship-repair-processes-led-to-better-on-time-rates-more-realistic-schedules

———. 2022. “US Navy reveals ships facing potential decommissioning next year.” Defense News. Last modified April 4, 2022. https://www.defensenews.com/naval/2022/04/04/us-navy-reveals-ships-facing-potential-decommissioning-next-year/

Larter, David B. 2018. "The U.S. Navy's fleet is getting old. It might get a lot older." Defense News. https://www.defensenews.com/naval/2018/06/07/the-us-navys-ships-are-getting-old-they-might-be-getting-a-lot-older/

———. 2019. "Despite record budgets, the U.S. Navy is short hundreds of millions for maintenance." Defense News. https://www.defensenews.com/naval/2019/08/19/despite-record-budgets-the-us-navy-is-short-hundreds-of-millions-for-maintenance/

Maritime Goods. n.d. "What does void tank mean?" https://www.maritimegoods.com/en/word/void-tank-meaning.html?I=2336

Naval Sea Systems Command (NAVSEA). 2017. "Surface Maintenance Engineering Planning Program (SURFMEPP) Core Products. https://www.navsea.navy.mil/Home/Team-Ships/NAVSEA-21/SURFMEPP/CoreProducts/#:~:text=Technical%20Foundation%20Papers%3A%20The%20Technical,required%20to%20meet%20the%20ESL.

NAVSEA. 2021. "Duration Analysis: Process and Assumptions for March 2021, Quarterly Review." Presentation.

OPNAV N83 Letter 4700 for POM-23. 2021. "Representative Intervals, Durations, and Repair Man-Days for Depot Level Maintenance Availabilities of U.S. Navy Ships.

SEA21. 2021. "Duration Analysis, Process & Assumptions for March 2021 Quarterly Review." PowerPoint presentation.

Statistics How To. 2022. "Excel Regression Analysis Output Explained." https://www.statisticshowto.com/probability-and-statistics/excel-statistics/excel-regression-analysis-output-explained/

Southwest Regional Maintenance Center (SWRMC). 2021. "Duration Analysis: Process and Assumptions for March 2021, Quarterly Review" Presentation at Quarterly review.

SWRMC. n.d.a. "Who We Are." https://www.swrmc.navy.mil/about.html

———. n.d.b. "Our Products." https://www.swrmc.navy.mil/products.html

———. 2021. "RMC Bootcamp." Presentation.

Valdez, Guillermo "Memo." Master Scheduler. Personal communication. Jan-Aug 2022.

White, Matthew J. 2013. "An Analysis of CNO Availability Performance Metrics and their Relation to Availability Performance." Master's thesis, Naval Postgraduate School, Monterey, CA. http://hdl.handle.net/10945/34762

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California