NPS-LM-20-025

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## An Analysis of Critical Material Failures of the Close-in-Weapons-System Onboard U.S. Guided Missile Destroyers

December 2019


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Prepared for the Naval Postgraduate School, Monterey, CA 93943.

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# ABSTRACT

This thesis analyzes the current state of the Close-In Weapon System (CIWS) and decides what improvements can be used to improve system operational readiness and life-cycle support. Currently, CIWS is supported by a Readiness Based Sparing Model that has drawn criticism from senior naval leaders for the operational availability (Ao) that it provides. We analyze data to derive a list of five "key offenders" parts that heavily impact operational availability of CIWS. We also analyze how improving the sparing of these "key offenders" can potentially improve operational availability. Additionally, we analyze the timing of actual failures in the fleet. This paper addresses CIWS operational readiness and life-cycle support while exploring whether other processes can be used to improve the operational readiness of U.S. Guided Missile Destroyers' CIWS systems. The major findings of our research are as follows: first, timing "luck" of failures accounted for a 7% difference between the worst-case scenario downtime and actual downtime. Second, that actual system availability was 86% of calendar days over fiscal years 2017 and 2018, exceeding NSWC's Ao predictions. Third, that the top five "key offenders" of which these parts can potentially affect account for a 3% improvement to operational downtime. Finally, that 10 of the 67 ships showed no downtime associated with CIWS, which could be a result of operational schedules.

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# ABOUT THE AUTHORS

**LT Edward Arca** is a Supply Officer. He was commissioned through Officer Candidate School at Newport, RI. His prior assignments was Food Service and Sales Officer onboard USS Antietam. Officer in Charge at ASD Guam, and Supply Officer onboard USS Higgins. After graduating from the Naval Postgraduate School he will transition to the civilian workforce.

**LCDR Matthew Carroll** is currently a graduate student at the Naval Postgraduate School in Monterey, CA, pursuing his Masters of Business Administration in the Acquisition & Contract Management (815) program. He was commissioned in the Navy Supply Corps upon completion of Officer Candidate School in October 2006. He holds a BS in Computer Engineering and a MS in Management from New York University (formerly Polytechnic University).

His operational and sea assignments include duties as the Supply Officer of the USS ASHEVILLE (SSN 758), and as the Combat Service Support Troop Commander (N4), SEAL Team FIVE, finally as the Afghan National Police (ANP) Fuels Officer, NATO Training Mission-Afghanistan/Combined Security Transition Command-Afghanistan, Kabul. His shore assignments includes the Naval Consolidated Brig Miramar, and Commander Submarine Squadron Fifteen in Agana, Guam.

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He is married to the former Melanie Mineroff of Brooklyn, NY. They have two girls, Lily and Madison.

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Hughes' operational assignments include: Supply Officer aboard USS HAWAII (SSN 776), which included the first deployment of a Virginia Class submarine to the Western Pacific. Stock Control Officer and Aviation Stores Officer aboard USS BATAAN (LHD 5), supporting a 2017 deployment to 5th and 6th fleets and a 2018 DPMA. Additionally, in 2014 he was selected to fill a temporary assignment as Supply Officer aboard USS MUSTIN (DDG 89) where he prepared the ship for a Western Pacific deployment in a critically gapped billet.

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LCDR Hughes' awards include three Navy and Marine Corps Commendation Medals and two Navy and Marine Corps Achievement Medals.

# ACKNOWLEDGMENTS

We would like to offer our sincere thanks to Professors Ryan Sullivan and Daniel Reich for their guidance, mentorship, and patience throughout this entire process.

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Last, we thank our families for their patience and support for us. This would not be possible without their enduring love and understanding.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AAW | Anti-Air Warfare |
| AAVT | Automatic Acquisition Video Tracker |
| Ao | Operational Availability |
| APDS | Armor Piercing Discarding Sabot |
| APL | Allowance Parts List |
| ASCM | Anti-Ship Cruise Missiles |
| ASUW | Anti-Surface Warfare |
| CASREP | Casualty Report |
| CIWS | Close-In Weapon System |
| CO | Commanding Officer |
| CNSF | Commander Naval Surface Forces |
| CWT | Customer Wait Times |
| CY | Calendar Year |
| DAU | Defense Acquisition University |
| DDG | Guided Missile Destroyer |
| DoD | Department of Defense |
| EO | Electro-Optic |
| FAR | Federal Acquisition Regulation |
| FDP | Forward Distribution Point |
| FLC | Fleet Logistic Center |
| FLIR | Forward Looking Infrared Radar |
| FTSCLANT/PAC | Navy Fleet Technical Support Center Atlantic/Pacific |
| FY | Fiscal Year |
| HOLC | High Order Language Computer |
| IR | Infrared |
| ISEA | In-Service Engineering Agent |
| IWST | Integrated Weapons System Team |
| JCN | Job Control Number |
| MLDT | Mean Logistics Delay Time |
| MTR | Mean Restoration Time |
| MTBF | Mean Time Between Failure |
| MTTR | Mean Time to Repair |
| NAVARM | Navy Aviation RBS Model |
| NAVICP | Navy Inventory Control Point |

| | |
|---|---|
| NAVSUP | Naval Supply Systems Command |
| NIIN | National Item Identification Number |
| NORS | Not Operationally Ready Supply |
| NPS | Naval Postgraduate School |
| NSLC | Naval Sea Logistics Center |
| NSN | National Stock Number |
| NSWC | Naval Surface Warfare Center |
| OR | Operational Research |
| PBL | Performance-Based Logistics |
| PEO | Program Executive |
| PSUM | Phalanx Surface Mode |
| RBS | Readiness-Based Sparing |
| SDP | Strategic Distribution Point |
| SUPPO | Supply Officer |
| TYCOM | Type Commander |
| WSS | Weapons System Support |
| USS | United States Ship |
| UMMIPS | Uniform Material Movement and Issue Priority System. |

# I. INTRODUCTION

The United States Navy is currently the world's largest, most powerful, and most technologically advanced Navy. Although other countries' navies are rapidly expanding and becoming more formidable, the United States continues to dominate the seas. To emphasize the Navy's dominance, the Navy's mission statement states, "The mission of the Navy is to maintain, train, and equip combat-ready naval forces capable of winning wars, deterring aggression, and maintaining freedom of the seas" (Military.com, n.d.).

One weapon that allows the U.S. Navy to continuously accomplish this mission is the Phalanx Close-In Weapon System (CIWS). The CIWS is a powerful defensive weapon that protects the surface fleet from airborne and surface threats. The CIWS is a mission-critical system that enables the Navy to operate in any environment without worrying about offensive threats. Although the CIWS is a strong defensive weapon, throughout its lifespan, the fleet has experienced logistics and sustainment issues with the CIWS, which is greatly affecting its operational availability (Ao). Both anecdotal evidence and research from Apte and Rendon (2009) regarding the CIWS imply that the system has a reputation for being unreliable. The CIWS system dates to 1980 and has gone through several generations of improvements. In the last decade, analysis from Apte (2004 & 2009), Chaparro (2003), and Rendon (2009) has been undertaken to examine costs, Ao, life-cycle support, and logistics. This information helped shape our own conclusions and recommendations.

The objective of this thesis is to analyze the current state of the CIWS and apply data analysis to improve our understanding of Ao and identify life-cycle support opportunities for the system. Currently the CIWS is supported by a Readiness-Based Sparing (RBS) model, which has drawn some criticism from senior naval leaders for the Ao it currently provides. In this paper, we explore whether different approaches and processes can be used to improve Ao, specifically for U.S. Guided Missile Destroyers (DDG), which account for the majority of CIWS usage fleetwide.

We gathered unclassified demand data from three primary sources:

1. Naval Surface Warfare Center (NSWC) Corona Division's top 20 Anti–Air Warfare and Anti–Surface Warfare CIWS offenders from Fiscal Year (FY) 2014 through FY2018 (Guided Missile Destroyers only)

2. Naval Supply Systems Command (NAVSUP) Weapon Systems Support (WSS) Common Electronics Integrated Weapons System Team's Major Critical and Critical Major Minor Demand from FY2017 and FY2018

3. Commander Naval Surface Forces Atlantic (CNSF) Supply Management Office's CIWS demand history from Calendar Year (CY) 2014 to CY2019.

We utilized NSWC Corona's listings of the top 20 offenders to CIWS Ao as the starting point for our data processing. We then screened NSWC's listing of offenders against the historical demand data provided by NAVSUP WSS and CNSF to develop a listing of our top five key offenders where we expect a high likelihood that allowancing measures will improve the material availability of the CIWS. Our research reviews other naval acquisition contracts, commercial weapon solutions as well as contracting techniques, to find improvements to the life-cycle support of the CIWS. These proposed solutions can offer different perspectives into providing superior service to our warfighters. We are not aware of any previous attempts to use multiple data sets to find "key offenders" and utilize data analysis and private sector solutions in order to increase Ao. Finally, we take a neutral look at the data without organizational pressures and then provide financially feasible recommendations to improve Ao for the CIWS.

The major findings of our research are as follows: first, timing "Luck" of failures accounted for a 7% difference between the worst-case scenario downtime and actual downtime over fiscal years 2017 and 2018. Secondly, the actual system availability was 86% of calendar days during that two year span, exceeding NSWC's Ao predictions. Third, the top five key offenders of which these parts can potentially account for a 3% improvement to operational downtime. Finally, 10 of the 67 ships showed no downtime associated with CIWS which could be a result of operational schedules.

In Chapter II, we describe the current state of CIWS, its employment, detailed history, and evolution of the CIWS system. We then go into the life-cycle support of the CIWS. Chapter III discusses the data sets and the methodology of combining three different data sets into a clean and coherent data set that can be analyzed. Chapter IV discusses the results of our data analysis. Our final chapter discusses our overall conclusions and recommendations for the project.

# II. BACKGROUND

The background chapter provides a broad introduction and history of the CIWS weapon system and naval supply history. The system's capabilities and how it is typically employed throughout the fleet are discussed. This discussion also covers the current state and supply procedures and details about the current state of life-cycle support for the CIWS. This chapter also contains a discussion of how Naval Systems Supply Command, (NAVSUP) provides logistical support to the CIWS via contracting. This leads into a discussion of how supply officers afloat also directly affect the life-cycle sustainment and how each of these factors affects the Ao of the system.

## A. THE CLOSE-IN WEAPON SYSTEM

The Close-In Weapon System is a defensive weapon used in the United States Navy to defend against incoming airborne and missile threats. Originally called the Block 0, the system was developed in the 1970s and was "designed to defeat low-altitude anti-ship cruise missiles (ASCMs). As anti-ship cruise missiles became more complex in maneuvers and ability to be detected, and warfare areas moved from open ocean to littoral environments, CIWS has evolved to meet the threat" (Pike, 2003).

> Essentially a Gatling gun, the CIWS is a fast-reaction, detect-through-engage, that can fire 4,500 rounds per minute. It has two modes, surface and airborne, which are used to detect incoming enemy aircraft and missiles. At sea, it is designed to defeat anti-ship missiles and close-in threats that have pierced other lines of defense. On land, as part of the U.S. Army's counter-rocket, artillery and mortar systems, it detects and destroys incoming rounds. It also helps provide early warning of attacks. (Raytheon, 2019)

It is commonly referred throughout the Navy as the "R2-D2" from the *Star Wars* movie franchise, due to its shape, as seen in Figures 1 and 2.

Figure 1. CIWS on the USS *Nimitz*. Source: U.S. Navy (2019).

Figure 2. CIWS on the USS *Wasp.* Source: U.S. Navy (2019).

## B. CURRENT STATE, HISTORY, AND EVOLUTION OF CIWS

The CIWS is currently employed on every type and platform of surface ship throughout the U.S. naval fleet. There are 217 systems onboard ships currently according to Jared Conley, who is the CIWS Program Manager in NAVSUP WSS Code N96162 (J. Conley, email to author, August 19, 2019). That number fluctuates as new ships are introduced and older ships are decommissioned.

The CIWS is a vital system that is required for passage through most major high-traffic sea lanes (e.g., Straits of Malacca). If the CIWS is not fully operational, a ship may not be able to defend against potential threats, thus affecting its operational capability. One of the U.S. Navy's key tenets is to ensure freedom of the seas, and if this weapon system is degraded, then the Navy potentially would not be able to accomplish its mission.

The technical specifications for the CIWS are shown in Table 1.

Table 1. Phalanx CIWS Specifications. Adapted from Pike (2003).

| **Primary Function** | **Anti-ship missile defense** |
|---|---|
| Contractor | Raytheon Systems Company<br>(formerly Hughes Missile Systems Company and purchased from General Dynamics Pomona Division in 1992) |
| Weight | 12,500 pounds (5,625 kg)<br>Later models 13,600 pounds (6,120 kg) |
| Range | Classified |
| Gun Type | M-61A1 Gatling |
| Type of Fire | 3,000 rounds per minute.<br>Later models 4,500 rounds per minute<br>(starting 1988 production, Pneumatic Gun Drive) |
| Magazine Capacity | 989 rounds<br>Later models 1,550 rounds |
| Caliber | 20mm |
| Ammunition | Armor Piercing Discarding Sabot (APDS),<br>Depleted Uranium or Tungsten sub-caliber penetrator |
| Sensors | Self-contained search and track radar |
| Search Radar | Ku-band; digital MTI |
| Track Radar | Ku-band; pulse Doppler monopulse |
| E/O Sensor | FLIR Imaging System with Automatic Tracker |
| Fire Control | Director with closed-loop spotting |
| Gun Drive | Pneumatic |
| Mount Drive | Electric |
| Date Deployed | 1980 (aboard USS *America*) |

The Block 0 was designed to defeat low altitude anti-ship cruise missiles. The first test platform for the weapon was onboard the USS *King* (DDG-41) in 1973. Based on this initial test, the Navy determined that the system needed additional improvements to increase performance and reliability.

Figure 3 illustrates the timeline of CIWS including upgrades.

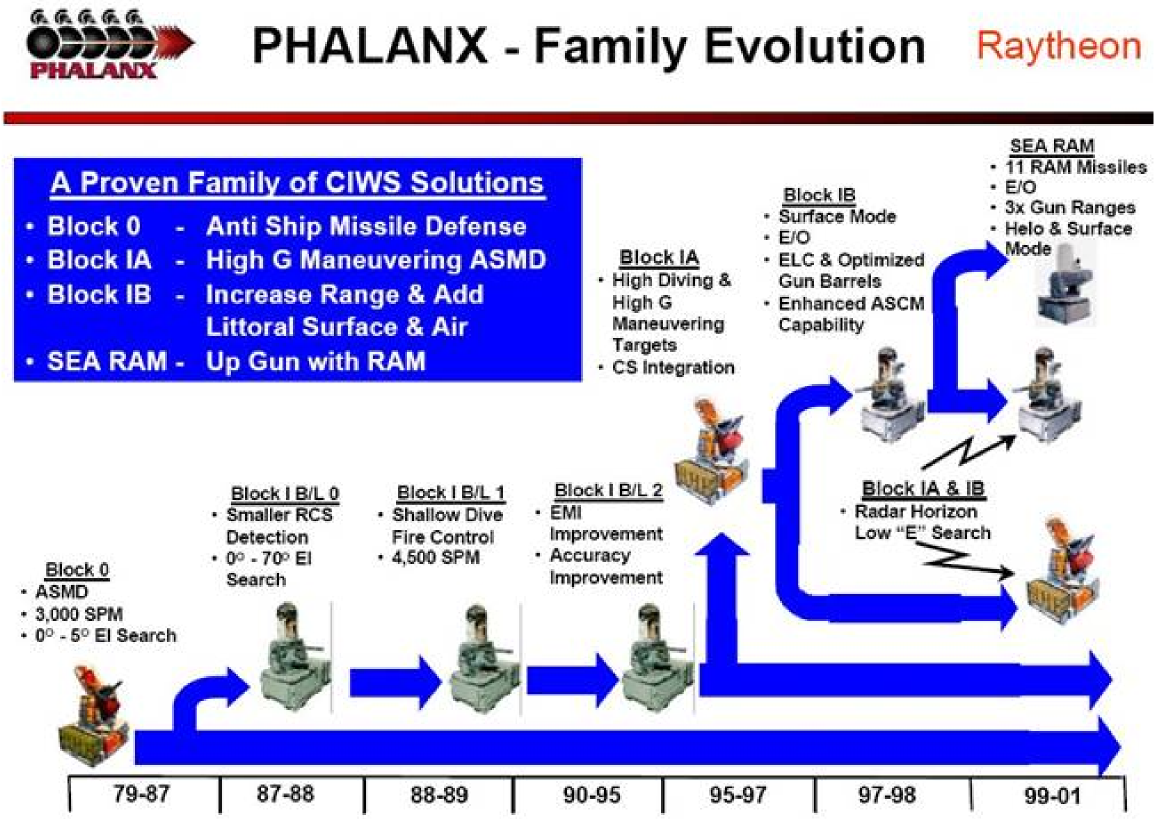



Figure 3. Phalanx Family Evolution. Source: (Stoner, N.D.)

Pike (2003) stated the following about the variations of the CIWS and improvements made to each variant of the system.

> Block 1 (Implemented 1987) incorporated a new search antenna to detect high altitude missiles, improve search sensitivity, and increase the ammunition available for firing by 50% through the use of a pneumatic gun drive that increased the firing rate to 4,500 rounds per minute, and started using tungsten ammunition as well as depleted uranium. Block I improvements provide increased elevation coverage, larger magazine space for increased round capacity, a variable and higher gun fire rate, and improved radar and processing capabilities.

> Block 1A (Implemented 1995) incorporated a new High Order Language Computer (HOLC) to provide more processing power over the obsolete general-purpose digital computer, improved fire control algorithms to counter maneuvering targets, search multiple weapons coordination to better manage engagements, and an end-to-end testing function to better determine system functionality.
>
> Block 1B Phalanx Surface Mode (PSUM) (Implemented 1997) incorporates a side mounted Forward Looking Infrared Radar (FLIR) which enables CIWS to engage low slow or hovering aircraft and surface craft. Additionally, the FLIR assists the radar in engaging some ASCMs bringing a greater chance of ship survivability. Block 1B uses a thermal imager Automatic Acquisition Video Tracker (AAVT) and stabilization system that provide surface mode and electro-optic (EO) angle track. These Block 1B enhancements provide day/night detection capability and enable the CIWS to engage small surface targets, slow-moving air targets, and helicopters.
>
> Baseline 2C (Implemented 1999) improvements provide an integrated multi-weapon operations capability, during integrated operations, the command system controls CIWS sensors, target reports, mode employment, and doctrine. The sensors are utilized to provide 360-degree search and track coverage, while providing track data to, and receiving designations from, the Command system. This CIWS installation includes a conversion kit for each weapon group to facilitate ease and safety of maintenance; the maintenance enclosure kit installs the below-deck equipment for a gun mount in a prefabricated enclosure with the mount located above it. (Pike, 2003)

## C. CIWS LIFE-CYCLE SUSTAINMENT AND SUPPORT

Any major military weapon system requires a tremendous amount of logistical support throughout the life of the weapon system. CIWS is no exception. Overall, the U.S. Navy's top echelon sustainment command, the Naval Supply Systems Command (NAVSUP), is responsible for the life-cycle support of the CIWS. NAVSUP is responsible for providing the full spectrum of logistical support and services to the warfighter. It is the business arm of the Navy and has the responsibility to ensure supplies, services, and quality of life necessities are being fulfilled. (For a complete history of NAVSUP, see Appendix A.) NAVSUP Weapons System Support (WSS) is working continuously with naval supply officers onboard surface vessels supporting and responding to CIWS system Ao.

> NAVSUP Weapon Systems Support provides program and supply support for the weapon systems that keep our naval forces mission ready, exercising centralized control of more than 375,000 different line items of repair parts,

> components, and assemblies providing global logistics support to our Navy's ships, aircraft, and weapon systems. (J. Derk, personal communication, August 8, 2019)

United States Naval ships operate 24 hours a day, seven days a week, 365 days a year. That is not possible without extensive logistical support worldwide. Naval supply officers serve onboard every Naval ship in the fleet. They are given extensive training and guidance on the fastest, most efficient ways in providing critical support when their ship calls for it.

From the authors experience as Navy supply officers, we are expected to execute a variety of missions, including supply management, expeditionary logistics, inventory control, disbursement, financial management, material and operational logistics, food service, and physical distribution. The overarching guidance for how exactly to operate onboard ships is the NAVSUP Publication 485, or P-485 as it is commonly referred to in the fleet.

The executive summary for the publication follows:

> Afloat Supply Procedures establishes policies for the operation and management of afloat supply departments and shore-based units of the fleet operating forces operating under afloat procedures. The procedures contained in this publication are the minimum essential acceptable supply management procedures and are mandatory unless specifically stated as being optional. (Department of the Navy [DoN], 1997)

The P-485 gives extremely detailed instruction on all the supply corps disciplines and explains the procedures for conducting inventories, ordering parts, responding to high-priority situations, and so on.

One of the most important functions faced by supply officers afloat is providing expedited logistical support for high-priority parts. When a major system aboard a ship (weapons, engineering, and communication) fails and the commanding officer determines that the ship cannot complete its mission, a report is generated to tell higher echelon commands of the situation. This report is called a Casualty Report, or CASREP. The CASREP gives a detailed description of the problem, actions taken to correct the problem, and its impact on mission capability and logistical support, which directly affects Ao.

The supply officer has a critical part to play in the CASREP process. In the supply section of the CASREP, logistics specialists will include part information and a requisition that is vital to the ship correcting the problem and returning to full operational capability. The requisition is a specific type, the highest priority in the supply system called a *Not Operational Ready Supply*, or NORS, requisition. The NORS requisition is also known as a WHISKEY requisition. However, a WHISKEY requisition is the common term among Navy supply officers. In supply terms, NORS means that the ship needs the supply chain to direct its full attention to this critical part. Per instruction in the P-485, the supply system has 14 days to get that part to the ship, no matter where it is in the world. An experienced supply officer will know the system and key players and if in port, should be able to reduce that 14-day requirement significantly. The CASREP/NORS process is one of the most crucial for Naval ships being able to operate around the world at any given time. Naval supply officers have a direct effect on the overall CIWS system Ao.

> Operational availability of a system can be defined by the NSWC as the probability that the system capable of performing its specific function in its intended environment when called for at a random point in time. The Ao effects the ship or systems probable availability in a wartime mission vice observed calendar operation. (Naval Surface Warfare Center, 2018, p 5).

In our case, Ao, can be described as how much time the CIWS is functional versus how much it is down because of broken parts or maintenance.

The Operational Availability formula is

$$Ao = \frac{MTBF}{MTBF + MRT}$$

Where:

"MTBF is the mean time between failures, also referred to as mean time between critical failure. MRT is the mean restoration time. This typically consists of mean logistics delay time (MLDT), plus mean time to repair" (MTTR; Reliability Analytics Toolkit, 2019).

As discussed in the previous section, when a U.S. Navy Destroyer CIWS has a repair parts failure that results in a CASREP, we make the assumption that the entire CIWS is down and not operational. This would mean the system is down, which in turn is affecting Ao. As we discuss the key offenders and the complete data sets, these parts are affecting the downtime/uptime and Ao of the system.

The acquisition tool that provides the life-cycle support for the CIWS is a Performance Based Logistic Contract (PBL). According to Defense Acquisition University (DAU) (2013), Performance Based Logistics is defined as the following:

> Performance Based Logistics (PBL)—PBL is synonymous with performance-based life-cycle product support, where outcomes are acquired through performance-based arrangements that deliver Warfighter requirements and incentivize product support providers to reduce costs through innovation. These arrangements are contracts with industry or inter-governmental agreements. Attributes of an effective PBL arrangement include:
>
> - Objective, measurable work description that acquires a product support outcome.
> - Appropriate contract length, terms, and funding strategies that encourage delivery of the required outcome
> - A manageable number of metrics linked to contract requirements that reflect desired Warfighter outcomes and cost reduction goals.
> - Incentives to achieve required outcomes and cost-reduction initiatives.
> - Risks and rewards are shared between government and commercial product support integrators and providers.
> - Synchronization of product support arrangements to satisfy Warfighter requirements. (Defense Acquisition University [DAU], 2013)

The overall picture of support from product support providers to the warfighter can be seen in Figure 4. Currently the CIWS is supported by NAVSUP WSS via a PBL contract.

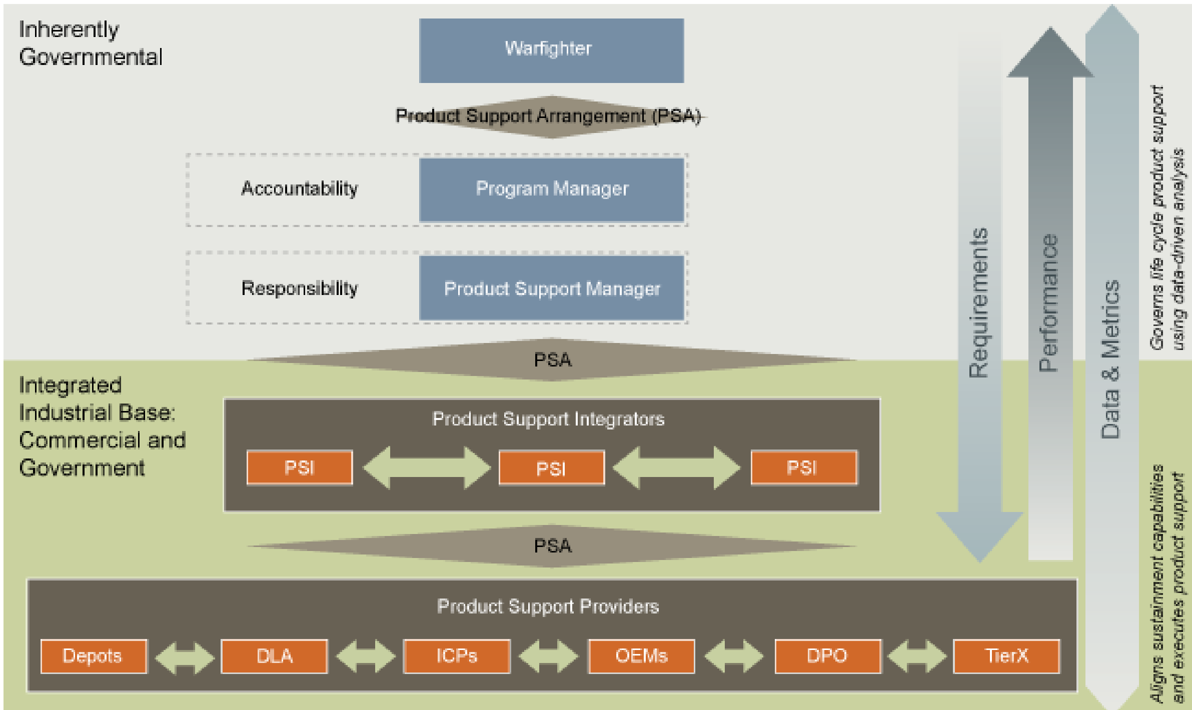



Figure 4. Product Support Business Model. Retrieved from Department of Defense (2011)

## D. LITERATURE REVIEW

There has been a significant amount of literature written about the CIWS, its associated costs and availability, life-cycle support, and modeling for the system. We focus on three articles of related research:

- A Diagnostic Approach to Weapon System Life cycle Support: The Phalanx Close-in Weapon System (Apte & Rendon, 2009)
- An Analysis of Spending Patterns Associated with the Phalanx Close-In Weapon System (CIWS) Program (Chaparro, 2003)
- Optimizing Phalanx Weapon System Life-Cycle Support (Apte, 2004)

### 1. A Diagnostic Approach to Weapon System Life-Cycle Support: The Phalanx CIWS

Apte and Rendon's (2009) focus is to evaluate the current life-cycle support for the CIWS and examine costs, optimization, Ao, reliability metric, casualty reports, life-cycle support, and logistics. This research analyzes a more efficient way, given various operational factors, how to better provide critical life-cycle support to the CIWS.

> At the time this research (2009) was conducted, the Phalanx CIWS—based on the literature reviewed, data analyzed, and our communication with the Program Executive Offices (PEO) personnel—seemed to be caught in a vicious circle of high cost but low operational availability. (Apte & Rendon, 2009, p. 3)

The authors found that the life-cycle support for the CIWS cycle is costly and at times inefficient. The system is in a cycle of high costs but a low return on Ao.

### 2. An Analysis of Spending Patterns Associated with the PHALANX Close-In Weapon System CIWS Program

This December 2003 Naval Postgraduate School thesis by Michael Chaparro focuses on the spending patterns for the CIWS and identifies potential areas of investigation for cost savings. The data in this research covers FY1998–2003 and includes total costs, both government employee and contractor labor, travel, and material costs. Several government entities are considered, including In-Service Engineering Agent (ISEA), Navy Fleet Technical Support Center Atlantic and Pacific (FTSCLANT/PAC), and Naval Inventory Control Point (NAVICP), which is now known as WSS and Program Executive Offices.

Chaparro (2003) found that CIWS contracted labor support is costly and there is potential for cost savings. Through the five fiscal years studied (FY1998–2003), Chaparro found that labor cost spending was higher than what was planned for and expected.

### 3. Optimizing Phalanx Weapon System Life-Cycle Support

Apte's (2004) focus was to identify the weapon system's problem areas and suggest improvements for correcting those deficiencies. This article goes into the CIWS optimization, Ao, reliability metric, casualty reports, and life-cycle support.

Apte's main point of the research coincides with ours in that we both look at the lower Ao and rising costs and determine what can be done to improve these issues. The findings of this paper are as follows: "there is a high cost of maintenance for CIWS and an increase in CASREPs and tech assists leading to reduction of reliability" (Apte, 2004, p.26). This research was completed in 2004; however, the same issues continue to plague the CIWS weapon system 15 years later in 2019.

# III. DATA

Our primary goal of gathering historical demand data for CIWS material requirements is to establish a group of "key offenders" that we could use for further research and modeling. Key offenders were identified based primarily on the NSWC's top 20 reliability drivers and were analyzed considering Customer Wait Times (CWT) of more than 14 days, the total number of orders, and the total number of CASREP orders.

We gathered unclassified demand data from three primary sources: NSWC Corona Division's top 20 Anti–Air Warfare (AAW) and Anti–Surface Warfare (ASUW) CIWS failures from FY2014 through FY2018 (DDG only); NAVSUP Weapon Systems (WSS) Support Common Electronics Integrated Weapons System Team's (IWST) Major Critical and Critical Major Minor demand from FY2017 and FY2018; and Commander Naval Surface Forces Atlantic (CNSF) Supply Management Office's CIWS demand history from CY2014 to CY2019. Each data set contained limitations that are outlined in the following sections; however, we were able to find correlations among the data that allow for supported conclusions.

## A. NAVAL SURFACE WARFARE CENTER'S DATA

NSWC Corona provided its top 20 Anti–Air Warfare and Anti–Surface Warfare CIWS offenders from October 1, 2013, through September 30, 2018, specifically limited to the DDG platform. The distinction of Anti-Air and Anti-Surface offenders is based on the two primary defensive roles/modes that CIWS functions under. The data included nomenclatures, number of failures, the part number, and National Item Identification Number for "Major Critical" demands.

Additionally, NSWC provides top level metrics (Figures 5 and 6) that allow for trend analysis in terms of overall Ao, MTBF, and critical failures per year. We viewed the NSWC reliability driver data and its conclusions as the cornerstone for our follow-on analysis since NSWC Corona is a primary material availability assessment arm of the Department of the Navy. NSWC Corona's "reliability drivers" rankings (Tables 2 and 3) are based on the associated part's effect on system Operational Availability (Ao). Ao is defined by NSWC case as "the probability that the system capable of performing its specific function in its intended environment when called for at a random point in time. The Ao reflects the ship or systems probable availability in a wartime mission vice observed calendar operation" (Naval Surface Warfare Center, 2018).

Our limitations in using NSWC's data are threefold. First, the listing does not indicate whether the "reliability driver" can be solved by the stocking posture of replacement parts or whether the issues are design/engineering-related. Second, we do not have the granularity in this data to analyze CWT, which will be a key deciding factor in establishing our list of "key offenders." NSWC's data does take CWT into account in its calculation of Ao through Mean Logistics Delay Time (MLDT), but we are specifically concerned with delays of more than 14 days, which may not be completely visible in their calculations. Third, we do not have granularity on CASREP-specific failures to analyze. Again, similar to the CWT concern, NSWC does take CASREP failures into account, but they display the information at higher level conclusions, restricting our ability to perform further analysis. The NAVSUP WSS and CNSF data sets will allow us to confirm the issues of CWT and CASREP-related failures (Naval Surface Warfare Center, 2018).

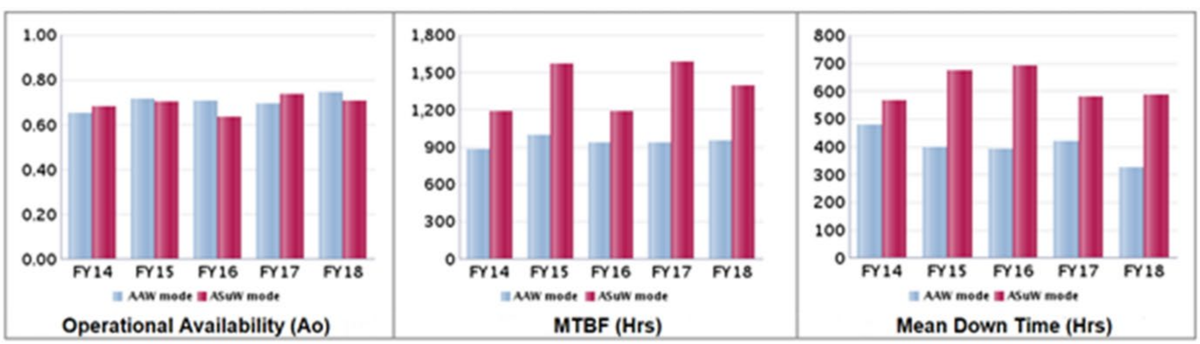
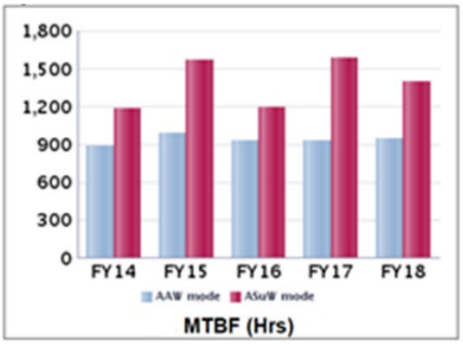



Figure 5. NSWC CIWS Top Level Metrics. Adapted from Naval Surface Warfare Center (2018).

Figure 5 shows fiscal years 2014 through 2018 top level metrics for both AAW and ASUW modes. In the figure, Ao remains relatively stable and improving over time, with ranges between .65 and .78. NSWC reports FY18Q4 Ao between .70 and .74. The MTBF chart shows higher mean times between failure and variability for the red ASUW mode when compared to the blue AAW. Similarly, the MDT chart shows consistently higher levels of down time for the ASUW mode over the four years measured.



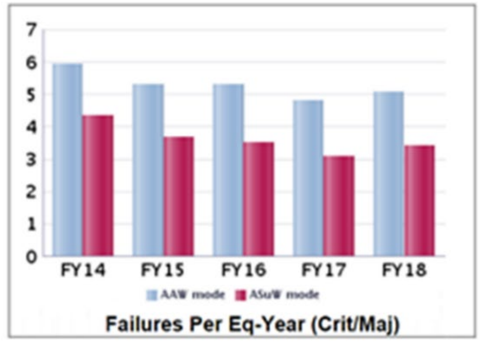




Figure 6. NSWC CIWS Reliability Metrics. Adapted from Naval Surface Warfare Center (2018).

Figure 6 shows reliability metrics for fiscal years 2014 through 2018 for both AAW and ASUW modes. Failures per Eq-Year shows a higher level of failures in the AAW mode versus the ASUW mode with an overall trend towards improvement in both categories.

Table 2. NSWC CIWS Reliability Drivers, DDG AAW. Adapted from Naval Surface Warfare Center (2018).

| Reliability Driver Ranking | Nomenclature | NIIN | # of failures |
|---|---|---|---|
| 1 | Rate Gyro | 011594340 | 161 |
| 2 | Motor Brush | 012458699 | 99 |
| 3 | Passive Limiter | 014142779 | 23 |
| 4 | IF Receiver CCA | 015611967 | 65 |
| 5 | DC Torque Motor | 012458725 | 88 |
| 6 | Coolant Pump | 013622973 | 88 |
| 7 | DC Drive Motor | 011572436 | 60 |
| 8 | Last Round Switch | 011547192 | 63 |
| 9 | Blower Motor | 012001689 | 40 |
| 10 | HPA | 014314290 | 43 |
| 11 | Exit Unit | 014867071 | 68 |
| 12 | Cutout Switch Assy | 011653830 | 29 |
| 13 | Rig Housing Assy | 012352929 | 32 |
| 14 | 20MM Gun Barrel | 014674261 | 11 |
| 15 | Slip Ring Assy | 012451898 | 37 |
| 16 | Scan Drive Assy | 013264156 | 28 |
| 17 | Grooved Coupling Clp | 011564079 | 36 |
| 18 | Switch Flow | 012187959 | 30 |
| 19 | Contactor Magnetic | 011888017 | 34 |
| 20 | Breech Bolt Assy | 010429821 | 51 |

Table 3. NSWC CIWS Reliability Drivers, DDG ASUW. Adapted from Naval Surface Warfare Center (2018).

| Reliability Driver Ranking | Nomenclature | NIIN | # of failures |
|---|---|---|---|
| 1 | Thermal Imager | 015582849 | 42 |
| 2 | Coolant Pump | 013622973 | 88 |
| 3 | DC Drive Motor | 011572436 | 60 |
| 4 | Last Round Switch | 011547192 | 63 |
| 5 | Rate Gyro | 011594340 | 41 |
| 6 | Blower Motor | 012001689 | 40 |
| 7 | Exit Unit | 014867071 | 68 |
| 8 | Cutout Switch Assy | 011653830 | 29 |
| 9 | 20MM Gun Barrel | 014674261 | 11 |
| 10 | Grooved Coupling Clp | 011564079 | 36 |
| 11 | Switch Flow | 012187959 | 30 |
| 12 | Contactor Magnetic | 011888017 | 34 |
| 13 | Breech Bolt Assy | 010429821 | 51 |
| 14 | Pneumatic Motor | 013833198 | 39 |
| 15 | Sector Holdback Assy | 007835504 | 29 |
| 16 | 20MM M61A1 Gun | 014865515 | 31 |
| 17 | Safety/Display CCA | 015434201 | 19 |
| 18 | Resistor Variable | 011653831 | 9 |
| 19 | Solenoid Assembly | 007545269 | 19 |
| 20 | Status Monitor CCA | 012346892 | 11 |

Table 2 and Table 3 are NSWC's listed reliability drivers for both ASUW and AAW modes. While the tables list failures as one of the metrics that NSWC assesses, they additionally take into account Ao, MTBF, and MDT when ranking the parts as reliability drivers. This is illustrated with the thermal imager ranking as NSWC's highest reliability driver, while not having the highest amount of failures listed.

## B. NAVSUP WSS FY2017 AND FY2018 CIWS DEMANDS

The NAVSUP Weapon Systems Support Common Electronics Integrated Weapons System (WSS) Team provided Major Critical and Critical Major Minor demand for FY2017 and FY2018. The data included Job Control Numbers (JCNs), start and end dates for the orders, part numbers, nomenclatures, and national stock numbers. The data covered a total of 9,334 orders made over the two fiscal years for all classes of naval ships.

As our research is focused on allowancing measures to combat CASREPs, we focused processing on the "Major Critical Category." Orders were sorted into DDG platform specific demands. Customer Wait Time was calculated for NSWC's top 20

Reliability Drivers as both an average CWT and number of orders delayed more than 14 days. The 14-day cutoff is being used as the established Uniform Material Movement and Issue Priority System (UMMIPS) response time standard for requisitions with priorities 01–03 ranges between four and 14 days depending on the ordering unit's location. By this standard, a response time greater than 14 days is a failure by the supply system, no matter where the unit is located.

## C. CNSL SUPPLY MANAGEMENT OFFICE'S DATA

The Commander Naval Surface Forces Atlantic (CNSF) Supply Management Office's CIWS provided CIWS demand history from CY2014 to May 1, 2019. The data included 169,003 orders from all Naval platforms and was broken into National Item Identification Number, Quantity Ordered, Date of Demand, CWT (in hours), Allowance Parts List (APL), Urgency of Need indicator, Price, and Ordering Unit. We regarded the accuracy of the data as low, since there is clearly a significant number of orders included that were unrelated to the CIWS system. The data did, however, include a large date range and key pieces of information, such as the Urgency of Need indicator, that would allow order classification into CASREPs, and demand dates and ordering units that would allow us to cross demands over to the NAVSUP WSS data.

Due to our concern over the quality of this data set, we are only utilizing it to confirm conclusions based on the two previous data sources. We processed the data by first separating information believed to be related to CIWS from clearly unrelated demand information and then removed demands unrelated to the DDG platform. DDG-specific demands for NSWC's Reliability Driver National Item Identification Numbers (NIINs) were then assessed for the number of Urgency of Need "A" orders indicating a CASREP-related demand.

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# IV. DISCUSSION AND ANALYSIS

Our discussion and analysis focus is on calculating downtime associated with the CIWS on DDGs, identifying our top five "key offenders," and understanding the role that our "key offenders" play in CIWS operational downtime. We close the chapter with a discussion of potential drivers

## A. CIWS PARTS ANALYSIS

Our analysis is based on three key processes. First, using the NAVSUP WSS FY17 and FY18 data, we reveal the amount of downtime each DDG unit's CIWS had over the two-year period, the potential worst-case scenario, and the percentage of time the ship's CIWS was operational. Second, using a combination of the three data sources, we identify five key offenders that are negatively affecting the operational readiness of CIWS and show a likelihood that greater spares funding and allowancing could improve operational readiness. Third, we analyze the operational downtime related specifically to our key offenders and how related spares allowancing may potentially improve overall CIWS operational readiness.

## B. DDG MAJOR CRITICAL CIWS DOWNTIME

The downtime analysis takes major critical material failures and their associated time from failure to repair to establish a "downtime" calculation (in days). The "Downtime (Actual)" column takes into account that some failures occurred over the same time period as other failures by overlaying repair timelines and not double-counting two repairs that were taking place at the same time. The "Downtime (Worst Case)" column is a calculation of how many days could have been lost if the failures were sequenced so that there were no overlapping timelines and each failure occurred after the previous failure had been correct. The "Operationally Avail (%)" column is a calculation of the percentage of total available days over the two-year period that the CIWS was operating without a Major Critical material failure. This data is listed in Table 4 by each DDG.

Table 4. DDG CIWS Major Critical Downtime

| Ship | Hull Number | Downtime (Actual) | Downtime (Worst Case) | Operational Avail |
|---|---|---|---|---|
| USS *Arleigh Burke* | DDG-51 | 310 | 352 | 57.5% |
| USS *Barry* | DDG-52 | 0 | 0 | 100.0% |
| USS *John Paul Jones* | DDG-53 | 0 | 0 | 100.0% |
| USS *Curtis Wilbur* | DDG-54 | 121 | 154 | 83.4% |
| USS *Stoute* | DDG-55 | 149 | 256 | 79.5% |
| USS *John S. McCain* | DDG-56 | 95 | 120 | 86.9% |
| USS *Mitchser* | DDG-57 | 284 | 535 | 61.1% |
| USS *Laboon* | DDG-58 | 144 | 169 | 80.2% |
| USS *Russell* | DDG-59 | 19 | 20 | 97.4% |
| USS *Paul Hamilton* | DDG-60 | 79 | 109 | 89.1% |
| USS *Ramage* | DDG-61 | 53 | 85 | 92.7% |
| USS *Fitzgerald* | DDG-62 | 0 | 0 | 100.0% |
| USS *Stetham* | DDG-63 | 243 | 625 | 66.7% |
| USS *Carney* | DDG-64 | 139 | 239 | 80.9% |
| USS *Benfold* | DDG-65 | 53 | 55 | 92.7% |
| USS *Gonzalez* | DDG-66 | 146 | 165 | 80.0% |
| USS *Cole* | DDG-67 | 294 | 488 | 59.7% |
| USS *The Sullivans* | DDG-68 | 178 | 275 | 75.6% |
| USS *Milius* | DDG-69 | 184 | 216 | 74.7% |
| USS *Hopper* | DDG-70 | 0 | 0 | 100.0% |
| USS *Ross* | DDG-71 | 104 | 113 | 85.7% |
| USS *Mahan* | DDG-72 | 71 | 86 | 90.2% |
| USS *Decatur* | DDG-73 | 233 | 413 | 68.0% |
| USS *McFaul* | DDG-74 | 47 | 53 | 93.5% |
| USS *Donald Cook* | DDG-75 | 245 | 493 | 66.4% |
| USS *Higgins* | DDG-76 | 143 | 195 | 80.4% |
| USS *O'Kane* | DDG-77 | 127 | 138 | 82.6% |
| USS *Porter* | DDG-78 | 59 | 85 | 91.9% |
| USS *Oscar Austin* | DDG-79 | 163 | 175 | 77.6% |
| USS *Roosevelt* | DDG-80 | 127 | 262 | 82.6% |
| USS *Winston S. Churchill* | DDG-81 | 354 | 611 | 51.5% |
| USS *Lassen* | DDG-82 | 53 | 54 | 92.7% |
| USS *Howard* | DDG-83 | 92 | 170 | 87.4% |
| USS *Bulkeley* | DDG-84 | 178 | 336 | 75.6% |
| USS *McCampbell* | DDG-85 | 25 | 30 | 96.5% |
| USS *Shoup* | DDG-86 | 174 | 382 | 76.1% |
| USS *Mason* | DDG-87 | 96 | 204 | 86.8% |
| USS *Preble* | DDG-88 | 101 | 176 | 86.1% |
| USS *Mustin* | DDG-89 | 0 | 0 | 100.0% |
| USS *Chafee* | DDG-90 | 54 | 79 | 92.6% |
| USS *Pinckney* | DDG-91 | 0 | 0 | 100.0% |
| USS *Momsen* | DDG-92 | 0 | 0 | 100.0% |

| Ship | Hull Number | Downtime (Actual) | Downtime (Worst Case) | Operational Avail |
|---|---|---|---|---|
| USS *Chung-Hoon* | DDG-93 | 39 | 54 | 94.6% |
| USS *Nitze* | DDG-94 | 31 | 32 | 95.7% |
| USS *James E. Williams* | DDG-95 | 74 | 170 | 89.8% |
| USS *Bainbridge* | DDG-96 | 149 | 174 | 80.8% |
| USS *Halsey* | DDG-97 | 23 | 23 | 96.8% |
| USS *Forrest Sherman* | DDG-98 | 69 | 70 | 90.5% |
| USS *Faragut* | DDG-99 | 91 | 93 | 87.5% |
| USS *Kidd* | DDG-100 | 58 | 95 | 92.0% |
| USS *Gridley* | DDG-101 | 0 | 0 | 100.0% |
| USS *Sampson* | DDG-102 | 95 | 102 | 86.9% |
| USS *Truxtun* | DDG-103 | 37 | 47 | 94.9% |
| USS *Sterett* | DDG-104 | 50 | 58 | 90.9% |
| USS *Dewey* | DDG-105 | 136 | 138 | 81.3% |
| USS *Stockdale* | DDG-106 | 65 | 118 | 91.1% |
| USS *Gravely* | DDG-107 | 85 | 91 | 88.3% |
| USS *Wayne E. Meyer* | DDG-108 | 113 | 119 | 84.5% |
| USS *Jason Dunham* | DDG-109 | 138 | 241 | 81.1% |
| USS *William P. Lawrence* | DDG-110 | 235 | 290 | 67.8% |
| USS *Spruance* | DDG-111 | 72 | 75 | 90.1% |
| USS *Michael Murphy* | DDG-112 | 82 | 111 | 88.7% |
| USS *John Finn* | DDG-113 | 35 | 65 | 95.2% |
| USS *Ralph Johnson* | DDG-114 | 3 | 3 | 99.5% |
| USS *Rafael Peralta* | DDG-115 | 59 | 65 | 91.9% |
| USS *Thomas Hudner* | DDG-116 | 0 | 0 | 100.0% |
| USS *Paul Ignatius* | DDG-117 | 0 | 0 | 100.0% |
| | Total Down Days | 6676 | 10152 | |
| | Available Days | 48910 | 48910 | |
| | Operational Avail (%) | 0.86 | 0.79 | |
| | MEAN | 99.6 | 151.5 | |
| | STD DEV (Pop) | 83.9 | 151.2 | |
| | Sample Size | 67 | 67 | |

Table 4 is the downtime review of DDGs over the fiscal years 2017 and 2018. The mean actual downtime was 99 days with DDGs being operationally available 86% of days during the reviewed time period. In the worst-case assessment, the same failures could have resulted in a mean downtime of 151 days which would have lowered the operationally available days 7% over the same time period. Of the 67 ships assessed, 10 of them showed no downtime associated with the CIWS which may be the result of operational schedules or maintenance periods, potentially impacting the CIWS metrics.

## C. PROJECT'S IDENTIFIED KEY OFFENDERS

A goal of the project is to identify repair parts that, with improved allowancing, could improve overall readiness of the CIWS program. The starting point for our identification of key offenders are the NSWC's top 20 reliability drivers. Tables 5 and 6 present the combined processed data from all three data sources and allow for us to draw conclusions regarding whether the "offender" can be impacted by allowancing choices. The "Avg CWT" is derived from the order to receipt processing time of the associated part and helps us recognize a potential stocking and allowancing deficiency. Similarly, the "# > 14 Days" helps identify an overall supply system response failure as defined by the NAVSUP P-485 and associated UMMIPS requirements. The "% UND A" is an acknowledgement of CASREP association in material ordering and helps further identify critical system parts.

Table 5. DDG AAW Combined Data Sets

| NSWC Ranking | Nomenclature | NIIN | # of failures (FY14–FY18) | Avg CWT (FY17 & FY18) | # > 14 Days (FY17 & FY18) | % UND A (CNAL Data) |
|---|---|---|---|---|---|---|
| 1 | Rate Gyro | 011594340 | 161 | 0.32 | 0 | 11.79 |
| 2 | Motor Brush | 012458699 | 99 | 2.29 | 2 | 4.61 |
| 3 | Passive Limiter | 014142779 | 23 | 5.54 | 2 | 16 |
| 4 | IF Receiver CCA | 015611967 | 65 | 24.87 | 6 | Not Listed |
| 5 | DC Torque Motor | 012458725 | 88 | 2.87 | 3 | 7.29 |
| 6 | Coolant Pump | 013622973 | 88 | 0.83 | 0 | 17.33 |
| 7 | DC Drive Motor | 011572436 | 60 | 6.91 | 4 | 24.66 |
| 8 | Last Round Switch | 011547192 | 63 | 3.75 | 2 | 11.29 |
| 9 | Blower Motor | 012001689 | 40 | 1.88 | 0 | 20.45 |
| 10 | HPA | 014314290 | 43 | 9.78 | 6 | 78.43 |
| 11 | Exit Unit | 014867071 | 68 | 13.08 | 8 | 73.17 |
| 12 | Cutout Switch Assy | 011653830 | 29 | 2.33 | 0 | 2.86 |
| 13 | Rig Housing Assy | 012352929 | 32 | 10.6 | 1 | 69.57 |
| 14 | 20MM Gun Barrel | 014674261 | 11 | 29 | 4 | Not Listed |
| 15 | Slip Ring Assy | 012451898 | 37 | 6.3 | 2 | 21.43 |
| 16 | Scan Drive Assy | 013264156 | 28 | 19.36 | 7 | 80.95 |
| 17 | Grooved Coupling Clp | 011564079 | 36 | 2.25 | 1 | 0 |
| 18 | Switch Flow | 012187959 | 30 | 0.75 | 0 | 9.09 |
| 19 | Contactor Magnetic | 011888017 | 34 | 7.38 | 3 | 15.63 |
| 20 | Breech Bolt Assy | 010429821 | 51 | 0 | 0 | 0 |

Table 6. DDG ASUW Combined Data Sets

| NSWC Ranking | Nomenclature | NIIN | # of failures (FY14–FY18) | Avg CWT (FY17 & FY18) | #>14 Days (FY17 & FY18) | # UND A (CNAL Data) |
|---|---|---|---|---|---|---|
| 1 | Thermal Imager | 015582849 | 42 | 26.12 | 16 | Not Listed |
| 2 | Coolant Pump | 013622973 | 88 | 0.82 | 0 | 17.33 |
| 3 | DC Drive Motor | 011572436 | 60 | 6.91 | 4 | 24.66 |
| 4 | Last Round Switch | 011547192 | 63 | 3.75 | 2 | 11.29 |
| 5 | Rate Gyro | 011594340 | 41 | 0.32 | 0 | 11.79 |
| 6 | Blower Motor | 012001689 | 40 | 1.88 | 0 | 20.45 |
| 7 | Exit Unit | 014867071 | 68 | 13.08 | 8 | 73.17 |
| 8 | Cutout Switch Assy | 011653830 | 29 | 2.33 | 0 | 2.86 |
| 9 | 20MM Gun Barrel | 014674261 | 11 | 29 | 4 | Not Listed |
| 10 | Grooved Coupling Clp | 011564079 | 36 | 2.25 | 1 | 0 |
| 11 | Switch Flow | 012187959 | 30 | 0.75 | 0 | 9.09 |
| 12 | Contactor Magnetic | 011888017 | 34 | 7.38 | 3 | 15.63 |
| 13 | Breech Bolt Assy | 010429821 | 51 | 0 | 0 | 0 |
| 14 | Pneumatic Motor | 013833198 | 39 | 19.19 | 9 | 84.21 |
| 15 | Sector Holdback Assy | 007835504 | 29 | 1.29 | 0 | 0 |
| 16 | 20MM M61A1 Gun | 014865515 | 31 | 6.2 | 12 | Not Listed |
| 17 | Safety/Display CCA | 015434201 | 19 | 4.3 | 1 | Not Listed |
| 18 | Resistor Variable | 011653831 | 9 | 0 | 0 | 0 |
| 19 | Solenoid Assembly | 007545269 | 19 | 1.67 | 0 | 0 |
| 20 | Status Monitor CCA | 012346892 | 11 | 1.83 | 0 | Not Listed |

Table 5 and Table 6 include NSWC's reliability drivers but account for logistics delays and stock availability. Of the 40 listed reliability drivers in the two tables, 16 of them met UMMIPS logistics time standards on every order and only four of the drivers had average CWT over the UMMIPS 14-day standard. The average CWT is a primary consideration in our assessing of how allowancing changes might impact overall Ao. Utilizing the information contained in Tables 5 and 6, we have identified the parts listed in Table 7 as key offenders and assess a high likelihood that stocking and allowancing measures would improve supply system response times, resulting in higher overall CIWS Ao.

Table 7. Key Offenders

| Nomenclature | NIIN | # of failures (FY14-18) | Avg CWT (FY17&18) | #>14 Days (FY17&18) | % UND A (CNAL Data) |
|---|---|---|---|---|---|
| Thermal Imager | 015582849 | 42 | 26.12 | 16 | Not Listed |
| IF Receiver CCA | 015611967 | 65 | 24.87 | 6 | Not Listed |
| Pneumatic Motor | 013833198 | 39 | 19.19 | 9 | 84.2 |
| Exit Unit | 014867071 | 68 | 13.08 | 8 | 73.2 |
| Scan Drive Assy | 013264156 | 28 | 19.36 | 7 | 81.0 |

Table 7 is our defined key offenders derived from NSWC's listing and accounting for logistics and stocking delays through CWT and delays over 14 days.

## D. DESCRIPTION OF KEY OFFENDERS

The below discussion of "key offenders" is provided to give the reader a clearer understanding of what these parts do and how they interact with the CIWS system.

### 1. Phalanx Thermal Imager

The Phalanx Thermal Imager is a Forward Looking Infrared (FLIR) system mounted on the Electro-Optical Stabilization Sub Assembly that allows for the viewing and recording of images from the mount. It operates in two field of view settings and has a digital view function. The price of the thermal imager is $342,394 without a carcass turn-in and $31,379 with one. There are currently eight thermal imagers held in the supply system. The system has a run life of 2,000–4,000 hours. This system is currently not covered under the PBL contract and is under a basic ordering agreement with Leonardo DRS. Conversations with the NAVSUP WSS CIWS Program Manager indicated that operators regularly use the thermal imager as a navigation tool, instead of its intended defense purpose, degrading the anticipated system run life. This part needs to be supported on a contract and include incentives for the contractor to decrease the time needed to get parts to the warfighters.

### 2. Circuit Card Assembly

The circuit card assembly upgraded circuit card that was added to the solid-state electronics suite which tripled the search range of the Phalanx system and reduced maintenance requirements. (M. A. Fahie, personal communication, October 10, 2019). The price of the circuit card assembly is $24,555 without a carcass turn-in and $10,692 with one. There are currently two of these circuit card assemblies in the supply system. Procurement lead time for a new (non-refurbished) circuit card assembly from Raytheon is 587 days. Due to the long lead time of this item, there should be more parts in the system since this is a high failure item. This part is supported by the PBL, and since it affects Ao, there needs to be incentivized language in the contract to decrease the time to get the part to the warfighter.

### 3. Pneumatic Motor

The pneumatic motor converts high-pressure air to a mechanical force that allows the barrel of the weapons system to spin at an extremely high rate allowing for the release of 4,500 rounds per minute (M. A. Fahie, personal communication, October 10, 2019). The price of the pneumatic motor is $351,117 without a carcass turn-in and $29,093 with one. There is currently one spare pneumatic motor in the supply system. Procurement lead time for a new (non-refurbished) pneumatic motor is 502 days. Due to the long lead time of this item, there should be more parts in the system since this is a high failure item. This part is supported by the PBL and since it affects Ao, there needs to be incentivized language in the contract to decrease the time to get the part to the warfighter.

### 4. Exit Unit

The exit unit is the assembly that allows the ammunition to exit the drum magazine and, in part, makes up the assembly where the CIWS drum is loaded. The exit unit is subject to significant wear and tear resulting from technicians loading the drum, which may impact the unit's useful life (M. A. Fahie, personal communication, October 10, 2019). The price of the exit unit is $169,003 without a carcass turn-in and $19,957 with one. There is currently one spare exit unit in the supply system. Procurement lead time for a new (non-refurbished) pneumatic motor from Raytheon is 548 days. Due to the long lead time of this item, there should be more parts in the system since this is a high failure item. This part is supported by the PBL, and since it affects Ao, there needs to be incentivized language in the contract to decrease the time to get the part to the warfighter.

### 5. Scan Drive

The scan drive is a brush motor used to allow the CIWS search antenna to spin (M. A. Fahie, personal communication, October 10, 2019). The price of the scan drive is $51,307 without a carcass turn-in and $29,079 with one. There are currently no scan drives in the supply system. Procurement lead time for a new (non-refurbished) scan drive from Raytheon is 1,032 days. Due to the long lead time of this item, it is clear that there should be more parts in the system since this is a high failure item. This part is supported by the PBL, and since it affects Ao, there needs to be incentivized language in the contract to decrease the time to get the part to the warfighter.

## E. KEY OFFENDERS' IMPACT ON DOWNTIME

The analysis of key offenders' impact on downtime is completed in a similar method to the larger analysis contained in Table 4. Table 8 adds in downtime related specifically to any of our five identified key offenders. This "Downtime (Key offenders)" is derived based on a worst-case assumption of material failures, which allows for comparison against the overall "Downtime (Worst Case)" and removes the potential for luck associated with the timing of failures to play a role in the analysis. The "Key offenders Impact" column is the percentage of failures during the two-year period that were associated to one or more of our key offenders.

Table 8. Key offenders' Impact on Downtime

| Ship | Hull Number | Downtime (Actual) | Downtime(Worst Case) | Downtime (Key Offenders) | Key Offenders Impact |
|---|---|---|---|---|---|
| USS Arleigh Burke | DDG-51 | 310 | 352 | 40 | 11.4% |
| USS Barry | DDG-52 | 0 | 0 | 0 | N/A |
| USS John Paul Jones | DDG-53 | 0 | 0 | 0 | N/A |
| USS Curtis Wilbur | DDG-54 | 121 | 154 | 38 | 24.7% |
| USS Stout | DDG-55 | 149 | 256 | 31 | 12.1% |
| USS John S. McCain | DDG-56 | 95 | 120 | 20 | 16.7% |
| USS Mitscher | DDG-57 | 284 | 535 | 26 | 4.9% |
| USS Laboon | DDG-58 | 144 | 169 | 7 | 4.1% |
| USS Russell | DDG-59 | 19 | 20 | 0 | 0.0% |
| USS Paul Hamilton | DDG-60 | 79 | 109 | 9 | 8.3% |
| USS Ramage | DDG-61 | 53 | 85 | 0 | 0.0% |
| USS Fitzgerald | DDG-62 | 0 | 0 | 0 | N/A |
| USS Stethem | DDG-63 | 243 | 625 | 37 | 5.9% |
| USS Carney | DDG-64 | 139 | 239 | 0 | 0.0% |
| USS Benfold | DDG-65 | 53 | 55 | 0 | 0.0% |
| USS Gonzalez | DDG-66 | 146 | 165 | 0 | 0.0% |
| USS Cole | DDG-67 | 294 | 488 | 59 | 12.1% |
| USS The Sullivans | DDG-68 | 178 | 275 | 120 | 43.6% |
| USS Milius | DDG-69 | 184 | 216 | 46 | 21.3% |
| USS Hopper | DDG-70 | 0 | 0 | 0 | N/A |
| USS Ross | DDG-71 | 104 | 113 | 52 | 46.0% |
| USS Mahan | DDG-72 | 71 | 86 | 12 | 14.0% |
| USS Decatur | DDG-73 | 233 | 413 | 80 | 19.4% |
| USS McFaul | DDG-74 | 47 | 53 | 0 | 0.0% |
| USS Donald Cook | DDG-75 | 245 | 493 | 102 | 20.7% |
| USS Higgins | DDG-76 | 143 | 195 | 21 | 10.8% |
| USS O'Kane | DDG-77 | 127 | 138 | 86 | 62.3% |
| USS Porter | DDG-78 | 59 | 85 | 9 | 10.6% |
| USS Oscar Austin | DDG-79 | 163 | 175 | 11 | 6.3% |
| USS Roosevelt | DDG-80 | 127 | 262 | 56 | 21.4% |
| USS Winston S. Churchill | DDG-81 | 354 | 611 | 59 | 9.7% |
| USS Lassen | DDG-82 | 53 | 54 | 16 | 29.6% |
| USS Howard | DDG-83 | 92 | 170 | 0 | 0.0% |
| USS Bulkeley | DDG-84 | 178 | 336 | 26 | 7.7% |
| USS McCampbell | DDG-85 | 25 | 30 | 0 | 0.0% |
| USS Shoup | DDG-86 | 174 | 382 | 85 | 22.3% |
| USS Mason | DDG-87 | 96 | 204 | 45 | 22.1% |
| USS Preble | DDG-88 | 101 | 176 | 16 | 9.1% |
| USS Mustin | DDG-89 | 0 | 0 | 0 | N/A |
| USS Chafee | DDG-90 | 54 | 79 | 0 | 0.0% |
| USS Pinckney | DDG-91 | 0 | 0 | 0 | N/A |
| USS Momsen | DDG-92 | 0 | 0 | 0 | N/A |
| USS Chung-Hoon | DDG-93 | 39 | 54 | 0 | 0.0% |
| USS Nitze | DDG-94 | 31 | 32 | 0 | 0.0% |
| USS James E. Williams | DDG-95 | 74 | 170 | 30 | 17.6% |
| USS Bainbridge | DDG-96 | 149 | 174 | 0 | 0.0% |
| USS Halsey | DDG-97 | 23 | 23 | 0 | 0.0% |
| USS Forrest Sherman | DDG-98 | 69 | 70 | 0 | 0.0% |
| USS Farragut | DDG-99 | 91 | 93 | 10 | 10.8% |
| USS Kidd | DDG-100 | 58 | 95 | 0 | 0.0% |
| USS Gridley | DDG-101 | 0 | 0 | 0 | N/A |
| USS Sampson | DDG-102 | 95 | 102 | 21 | 20.6% |
| USS Truxtun | DDG-103 | 37 | 47 | 15 | 31.9% |
| USS Sterett | DDG-104 | 50 | 58 | 42 | 72.4% |
| USS Dewey | DDG-105 | 136 | 138 | 0 | 0.0% |
| USS Stockdale | DDG-106 | 65 | 118 | 0 | 0.0% |
| USS Gravely | DDG-107 | 85 | 91 | 8 | 8.8% |
| USS Wayne E. Meyer | DDG-108 | 113 | 119 | 69 | 58.0% |
| USS Jason Dunham | DDG-109 | 138 | 241 | 58 | 24.1% |
| USS William P. Lawrence | DDG-110 | 235 | 290 | 0 | 0.0% |
| USS Spruance | DDG-111 | 72 | 75 | 27 | 36.0% |
| USS Michael Murphy | DDG-112 | 82 | 111 | 46 | 41.4% |
| USS John Finn | DDG-113 | 35 | 65 | 61 | 93.8% |
| USS Ralph Johnson | DDG-114 | 3 | 3 | 0 | 0.0% |
| USS Rafael Peralta | DDG-115 | 59 | 65 | 6 | 9.2% |
| USS Thomas Hudner | DDG-116 | 0 | 0 | 0 | N/A |
| USS Paul Ignatius | DDG-117 | 0 | 0 | 0 | N/A |
| | **Total Down Days** | 6676 | 10152 | 1502 | 14.8% |
| | **Available Days** | 48910 | 48910 | 48910 | |
| | **Operationally Avail (%)** | 86.4% | 79.2% | 96.9% | |
| | **MEAN** | 99.6 | 151.5 | 22.4 | |
| | **STD DEV (Pop)** | 84.0 | 151.2 | 28.9 | |
| | **Sample Size** | 67 | 67 | 67 | |

Table 8 assesses the impact of our 5 key offenders on overall DDG downtime. The table shows that the key offenders account for 3 percent of all CIWS downtime and account for 751 down days per year to the system. The *USS John Finn* was most effected by the key offenders with 94% of its downtime associated with our key offenders.

## F. DATA INACCURACIES AND DISTORTIONS

**Data Inconsistencies.** Our two large data sources for analysis were the NAVSUP WSS FY2017 and FY2018 CIWS Demands and CNSL Supply Management Office's Data. In processing the data, it became clear that significant inconsistencies existed between the two. As a small example, when limited to our top five key offenders listing, 6 UND "A" orders exist on the CNSL data set that are not reflected on the NAVSUP WSS data set and 27 Major Critical orders exist on the NAVSUP WSS that are not reflected on the CNSL data. We focused our research on the NAVSUP WSS data as they are an organization more focused on analytics than CNSL. **Institutional Language.** The NAVSUP WSS and NSWC Corona data was focused heavily on terms "Major Critical" and "Major Critical Minor." These terms are not defined or used in the NAVSUP P-485 and as a result, are not part of the operational supply officer's vernacular. The change in language separates associated shipping and processing requirements outlined in the NAVSUP P-485 from what are likely CASREP and UND "A" requirements.

**Cannibalizations.** Cannibalizing system parts from other weapons systems in the fleet is a relatively normal process for circumventing the supply system and bringing a priority ship to an operationally ready status. A cannibalization is the process of taking a working part from Ship A to fulfill a CASREP on Ship B. Ship B's WHISKEY Requisition will then be sent to Ship A as "Payback." Each cannibalization distorts impact of a material failure and the associated supply system response. It is recommended that future researchers examine cannibalization as a topic for future research. As per the P-485, "cannibalization is an extreme action and should be used only as a last resort" (DoN, 1997, p. 3004). The cannibalization process is regulated through the type commander (TYCOM), however there is no research on the costs and benefits of cannibalization.

**Distortions from Human Behavior.** In each step of the ordering and receipt process, there is the opportunity for a technician to fail to input key data in a timely manner.

This can have the impact of showing potentially significant delays or failures in the supply system when they don't exist. More experienced maintainers may be more adept to finding problems with a weapon system more efficiently than a maintainer who is less experienced. Preventing and communicating perceived demand signals when they are less urgent. Organizational pressure from the chain of command may pressure the maintainer and the supply system to bring the weapon system back online.

**Ship's Operational Schedule.** Operational schedules affect weapons systems use, failure rates, and logistics response times. As such, an operational schedule can make a weapons system appear to have distorted failure rates in a data set.

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# V. CONCLUSIONS AND RECOMMENDATIONS

The major findings of our research as follows: first, that timing "Luck" of failures accounted for a 7% difference between the worst-case scenario downtime and actual downtime. Second, NSWC's FY18Q4 report identifies an Ao between .70 and .74 for the system depending on system mode. This Ao is the predicted probability that the system is capable of performing its function when called upon. Our project calculated that the system was operationally available 86% of calendar days over fiscal years 2017 and 2018, showing that the CIWS actual performance exceeded the forecast by between 12% and 16% during those calendar years. Third, better allowancing for only the key offenders could potentially result in a 3 percent improvement to operationally available days or 751 more CIWS operational days per year. Finally, 10 of the 67 ships showed no downtime associated with CIWS which could be a result of operational schedules or maintenance periods that could potentially mask CIWS metrics.

After drawing the conclusions from the data analysis, we have developed several recommendations. First, increase funding for the CIWS and develop an RBS model similar to the NAVARM to allow for better cost-benefit analysis in sustaining the CIWS. The RBS model is owned by Raytheon and is not available for use to study allowancing, the inputs for parts, and other critical data that directly affects the Ao of the CIWS. Many government organizations and private companies utilize modern optimization models to increase logistical capability and reduce costs. These models do consider some of the factors previously discussed. In this era of fiscal responsibility, we as stewards of taxpayer's money must ensure we are efficient and get the best value for what we spend public funds on. Computer optimization models are often used to aid decision-makers choices

NPS OR professors Arnold Buss, Javier Salmeron, and John Wray were key contributors to a Readiness-Based Sparing Optimization model designed for the Naval Aviation community. The goal of the model was to help NAVSUP ensure the warfighter had the right material, at the right place, time, and price (Buss, Salmeron, & Wray, 2017). The simulation used mathematical models and computation tools to help make allowancing determinations for sparing to availability for tens of thousands repair parts (Buss et al., 2017). The model utilized the Ao formula discussed in CIWS Life-Cycle Sustainment section (2C) of this publication for the aviation community and essentially broke down the costs associated with increasing availability for each individual repair part in the simulation. This is a valuable tool for logistics personnel in trying to maximize readiness at the most cost and time efficient manner possible. We recommend a similar tool be developed for use in the Navy Surface community.

The second recommendation would be to adjust the next sustainment contract for the CIWS and try to adapt an incentivized contract, similar to ones that have been successful in the Naval aviation community. Department of Defense (DoD) acquisition personnel have a great burden to ensure they are being good stewards of these large amounts of public funds. There are specific contracts the government can use to accomplish this. The Federal Acquisition Regulation (FAR) Section 16, specifically section 16.401, states methods for incentivizing contracts. Contracts need to be written to reward contractors for providing service above and beyond those terms. A contractor who is incentivized for additional profit is motivated to provide better service.

The aviation community has several examples of incentivized PBL contracts that were regarded as successful, such as the E-2C tires, H-60 FLIR, and the Auxiliary Power Unit PBLs. "The goal of the PBL is to buy a comprehensive, performance-based contract that guarantees availability, improved reliability, and other desired logistics elements" (S. Brown, email to author, October 17, 2019). The challenge would be to ensure that clearly defined and executable metrics are communicated to the contractor and can be adequately managed by the Navy. The thermal imager is not under contract and cannot be adequately managed with any metrics. The first step may be to shift the thermal imager from a basic order agreement to a contract.

Another recommendation is to ensure the system is being used as intended. During our research for this project, we discovered that part of the issues with the CIWS is the weapon system is not being used as intended. Specifically, two of the five key offenders have high failure rates because they are being used in a capacity other than described by technical manuals.

The Thermal Imager and the Exit Unit are great examples of the CIWS not being used in the fleet as intended by the manufacturer. The Thermal Imager is an infrared (IR) camera, which improves visibility at night and during inclement weather. Because it has the capability to be used as a navigation tool rather than a weapon system, this has led to a higher failure rate because ships are using it to see during low visibility periods. The Exit Unit is where the ammunition is loaded and when fired exits the weapon. This is essentially a high usage area because sailors are constantly touching, loading, and cleaning the Exit Unit. This leads to higher failure rates because of human error. Using the system as intended will lead to a decrease in the number of failures, specifically with the Thermal Imager and the Exit Unit.

The U.S. Navy has been using the CIWS since the 1980s, and is a legacy weapon system. The CIWS is touted as the "Last Line of Defense," however as technology and new weapons advance, replacements should be explored. The CIWS can fire 4,500 rounds a minute at incoming threats; however, there are potentially missiles in use designed to defeat the CIWS. "More and more missiles today fly at supersonic speeds of up to Mach 2–3" (Milburn, 2016). A specific threat is China's DF-21 Missile, "Chinese DF-21 has the potential to strike American carriers from heretofore unrealizable ranges and threatens to penetrate existing defense systems" (Farley, 2019).

Consideration should be given to whether the CIWS can defeat these threats. It might be time for the CIWS to be replaced with a more capable system. Per F.A.R. Part 12, DoD Acquisitions should consider commercially available solutions. One system could be the Metal Storm. "Metal Storm is an Australian-made, U.S.-funded weapons system" (Milzarski, 2018). "The Metal Storm prototype was rated at 16,000 rounds per second or 1,000,000 rounds a minute" (Valle, 2016). In light of the new threats being employed by China, a new close in defense system with better capability needs to be researched as a possible replacement for the CIWS.

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# APPENDIX A. HISTORY OF NAVY SUUPLY SYSTEMS COMMAND

Janice Derk, NAVSUP PAO, provided us with a history of NAVSUP via personal communication on 8 August, 2019.

The Naval Supply Systems Command (NAVSUP) came into being officially on May 1, 1966, when the Bureau of Supplies and Accounts (BuSandA) was redesignated as NAVSUP. However, the command can trace its lineage directly back to February 1795, when the Office of Purveyor of Public Supplies was established.

At the formation of the Continental Navy during the early days of the American Revolution, the Continental Congress recognized immediately the need to be able to supply the budding fleet and adopted a system of obtaining materials and supplies similar to that employed by the British.

In 1794, construction of six new Navy ships, the first since the Revolution, was authorized by Congress, and responsibility for procurement of military supplies was given to Tench Coxe, the commissioner of revenue. Coxe, in turn, assigned the responsibility for procuring supplies for the shipbuilding project to Tench Francis, then serving as a Treasury Agent involved in purchasing military supplies.

Coxe relinquished his naval procurement duties in December 1794, and Tench Francis assumed these duties. Then, on February 23, 1795, Congress established, within the Department of the Treasury, the office of "Purveyor of Public Supplies." President Washington nominated, and the Senate confirmed, Tench Francis to the position. Tench Francis is the person to whom the Navy Supply Corps traces its beginnings.

Events of the ensuing decades, including the young nation's growing maritime responsibilities, saw the creation of a separate Navy Department. As the fleet grew, so did the responsibility to keep it supplied. In 1842, the Navy Department was reorganized establishing five Naval Bureaus, including the Bureau of Provisions and Clothing.

The bureau was made responsible for "accomplishment of the multitude of tasks associated with supply and fiscal support." Charles W. Goldsborough, a civilian, became the first chief of the bureau.

Over the next 50 years, successive chiefs of the bureau introduced improvements and innovations, such as the theory of contracting to the lowest bidder, rigid inspections of foodstuffs, and a comprehensive fleet supply.

On July 19, 1892, the Bureau of Provisions and Clothing changed its name to the Bureau of Supplies and Accounts. This change recognized the expansion of the bureau's interests beyond money, provisions and clothing, to encompass bookkeeping and supply work for the entire Navy and facilitated further refinement and innovation in the supply business.

## A. WORLD WAR I

World War I served as a proving ground for BuSandA's methods. In his annual report for 1918, Secretary of the Navy Josephus Daniels said, "There has been no confusion, no relaxation of any of the established safeguards against imposition and fraud. So far as practicable, everything has been bought—just as it always was—after open and public competition among manufacturers and regular dealers."

Despite the wartime surge, foresight and planning before the war enabled the bureau to meet its commitments to purchase, store, transfer, and account for naval supplies.

## B. WORLD WAR II

Where World War I was a demonstration of the effectiveness of proper planning, World War II became a test of the bureau's ability to adapt to rapidly changing circumstances under immense pressure in a true global environment.

As an illustration of the magnitude of the job, in December 1941, the Navy Supply Corps consisted of 2,200 officers of whom 1,400 were Reservists. By August 1945, there were 16,800 Supply Corps officers, 14,900 of whom were Reservists.

BuSandA employed 3,569 civilians in December 1941, 2,947 of whom were in the field. By August 1945, the bureau had 68,622 civilians, 65,511 of whom were in the field.

World War II brought along rapid innovations in all fields, including supply, and resulted, in 1947, in the establishment of an integrated Naval Supply System and the reorganization of BuSandA to administer this newly integrated system.

## C. KOREAN WAR

On June 25, 1950, North Korean troops attacked across the 38th parallel into South Korea and threatened to overrun the entire Korean peninsula. Two days later the United Nations authorized member states to take necessary action to repel the invaders. Navy supply operations managed to keep the United Nations Forces replenished using existing stowage facilities in Japan, reliance on Military Sea Transportation Service ships for resupply from the United States, and workable inter-service agreements. During the Korean War some recently deactivated supply bases were reactivated, and the Navy had to procure much of the same material it had disposed of after World War II.

Great leaps in technology since World War II have brought even more rapid change. The advent of the computer revolutionized the way all business is done. Computers made possible standardized supply operations at inventory control points, stock points, and on ships.

In 1966 a major reorganization of the Navy Department resulted in replacing the bureaus with systems commands.

Thus, when BuSandA became NAVSUP in May 1966, RADM H. J. Goldberg, Supply Corps, USN, became the last Chief of BuSandA, and Paymaster General, and the first Commander, NAVSUP, and Chief of Supply Corps.

Innovations and changes continued in the ensuing years, with the implementation of the first phase of a uniform inventory control point system.

## D. VIETNAM WAR

During the Vietnam War the impressive growth of the Navy Supply Depot Danang, the first major Navy Support Base in a combat zone, made it the largest single logistics support organization in U.S. history.

In 1968, because of its support to operating forces deployed to Western Pacific and Vietnam, Naval Supply Depot Subic Bay became the first ever NAVSUP-managed field activity to receive a Presidential Unit Citation.

In April 1969, NAVSUP Headquarters relocated, along with several other Navy activities, from its longtime home in the Main Navy Building at 18th and Constitution Avenue in the District of Columbia, to Crystal Mall 3 in Arlington, Virginia.

## E. THE 1970s

The decade of the 1970s saw some firsts for Navy supply as well as a period of austerity. In addition to significant cuts in military funding in the 1970s, 1973 saw a national energy crisis brought on by the Middle East oil embargo. NAVSUP was a leader in instituting both fuel economy programs for the Navy as well as procedures to eliminate or severely limit environmental contamination.

## F. THE 1980s

The early 1980s saw a national defense buildup, including the goal of a 600-ship Navy. The decade also saw United States involvement in a number of low intensity conflicts. NAVSUP provided petroleum support to the British Royal Navy during their 1982 conflict with Argentina in the Falkland Islands. In 1982, NAVSUP also played a key role in the reactivation of the Iowa Class battleships and in supporting Operation Urgent Fury in Granada.

## G. THE 1990s

The 1980s ended and the 1990s began with U.S. military forces in action. In December 1989, Operation Just Cause, was launched in Panama to capture accused drug trafficker Manuel Noriega. Just Cause carried into early 1990. Then, in August 1990, Iraqi forces invaded Kuwait, and Operation Desert Shield commenced, preventing further advance by Iraqi Forces. Desert Shield later became Desert Storm when U.S. and allied forces combined to oust the Iraqis from Kuwaiti territory.

During the Persian Gulf War, the Navy, aided significantly by the planning and efforts of NAVSUP, largely avoided the logistics difficulties encountered by the other services, because the fleet "operates in war as it does in peace—only the tempo of operations varies."

NAVSUP contributed significantly during Operation Restore Hope in Somalia in late 1992 and early 1993, particularly through the Naval Reserve Supply Corps Streamlined Automated Logistics Transmission System (SALTS) team, in establishing the area communications system.

In 1993, the Base Realignment and Closure Commission directed that NAVSUP relocate its headquarters from leased spaces in the National Capital Region to Navy-owned spaces in Mechanicsburg, PA. That move was completed on July 2, 1996, when NAVSUP raised its flag at its new headquarters facility at the Naval Inventory Control Point in Mechanicsburg.

## H. 2000 AND BEYOND

Since the end of the cold war, the size of the Navy's fleet has been reduced significantly from the close to 600-ship level of the mid-1980s. NAVSUP has a tradition of meeting the tests of dynamic operating and fiscal environments and remains dedicated to ensuring the Navy is ready to meet its mission. It is the resilience and adaptability of our supply community (civilian, active duty, and Reserve component) that allows us to overcome challenges, provide solutions, and deliver to our customer. NAVSUP sustains the fleet today, plans for tomorrow, and is always ready for sea. With headquarters in Mechanicsburg, Pennsylvania, and employing a diverse, worldwide workforce of more than 22,500 military and civilian personnel, the NAVSUP and Navy Supply Corps team share one mission—to provide supplies, services, and quality-of-life support to the Navy and Joint warfighter.

The NAVSUP/Navy Supply Corps team oversees a diverse portfolio including supply chain management for material support to Navy, Marine Corps, Joint and coalition partners, supply operations, conventional ordnance, contracting, resale, fuel, transportation, security assistance, and quality of life issues for our naval forces, including food service, postal services, Navy Exchanges, and movement of household goods.

In addition to its headquarters activity, the NAVSUP Enterprise is comprised 11 commands located worldwide.

NAVSUP Weapon Systems Support (NAVSUP WSS) provides program and supply support for the weapon systems that keep our naval forces mission ready, exercising centralized control of more than 375,000 different line items of repair parts, components, and assemblies providing global logistics support to our Navy's ships, aircraft, and weapon systems. NAVSUP WSS also provides logistics and supply assistance to coalition and allied nations through the Foreign Military Sales program.

NAVSUP Business Systems Center (NAVSUP BSC) delivers logistics information technology (LOG IT) solutions with specific emphasis on logistics and business-related products and services. This group is the Navy's premier central design agency with responsibility to design, develop, maintain and secure information systems support Department of Defense and International partners in the functional areas of logistics, supply chain management, transportation, finance, and accounting.

NAVSUP Fleet Logistics Centers (NAVSUP FLCs) deliver worldwide integrated logistics, contracting services, and products and services to facilitate transportation and ordnance to Navy and Joint operational units across all warfare enterprises and military operations. NAVSUP operates eight NAVSUP Fleet Logistics Centers located in Jacksonville, FL; Norfolk, VA; Pearl Harbor, HI; Puget Sound, WA; San Diego, CA; Sigonella, Italy; Yokosuka, Japan; and Manama, Bahrain.

Navy Exchange Service Command (NEXCOM) oversees 100 Navy Exchange (NEX) facilities and nearly 300 stores worldwide, 39 Navy Lodges, the Ships Store Program, the Uniform Program Management Office, the Navy Clothing and Textile Research Facility and the Telecommunications Program Office. NEXCOM's mission is to provide authorized customers quality goods and services at a savings and to support Navy quality of life programs for active duty military, retirees, Reservists, and their families. NEXs and Navy Lodges operate primarily as a nonappropriated fund business instrumentality. NEX revenues generated are used to support Navy Morale, Welfare, and Recreation programs.

# APPENDIX B. PYTHON SOURCE CODE

Following is the Python source code that was used to compile all CIWS data sets from NSWC Corona Division's top 20 Anti–Air Warfare and Anti–Surface Warfare CIWS offenders from FY2014 through FY2018 (DDG only); NAVSUP Weapon Systems (WSS) Support Common Electronics Integrated Weapons System Team's (IWST) Major Critical and Critical Major Minor demand from FY2017 and FY2018; and Commander Naval Surface Forces Atlantic (CNSF) Supply Management Office's CIWS demand history from CY2014 to CY2019.

> Python is an interpreted, object-oriented, high-level programming language with dynamic semantics. Its high-level built in data structures, combined with dynamic typing and dynamic binding, make it very attractive for Rapid Application Development, as well as for use as a scripting or glue language to connect existing components together. Python's simple, easy to learn syntax emphasizes readability and therefore reduces the cost of program maintenance. Python supports modules and packages, which encourages program modularity and code reuse. The Python interpreter and the extensive standard library are available in source or binary form without charge for all major platforms and can be freely distributed. (Python, 2019)

In order to conduct our data analyses, the three data sets referenced above needed to be filtered, merged, grouped, and cross referenced. Given the magnitude of the original data was too large for manual analysis and cleaning, Professor Daniel Reich assisted us in writing a Python computer program to prepare the data for analysis. This program allowed us to eliminate data that was not applicable to the project, focus on the most relevant date and conduct analyses from that data.

```
import pandas as pd
from pandas import ExcelWriter
from pandas import ExcelFile
from dateutil import parser
from datetime import datetime

def cleanRecord(record):
   for i in range(0, len(record)):
      if isinstance(record [i], str):
          record [i] = record [i].strip()
   record [‘Start’] = datetime.strptime(record [‘Start’], ‘%Y-%m-%d %H:%M:%S’).date()
```

```
    record ['End'] = datetime.strptime(record ['End'], '%Y-%m-%d %H:%M:%S').date()
    return record

def readWSSrecords(filterPart):
    dfWSS = pd.read_excel('Project Office Demand With Working Data 10–7-2019.xlsx',
sheet_name='FY17-18 Major Critical',
                          converters={'NSN':str, 'Start':str, 'End':str})
    recordListWSS = []
    for index, row in dfWSS.iterrows():
        if filterPart == None or row ['NSN'].endswith(filterPart):
            recordListWSS.append(cleanRecord(row))
    return recordListWSS

def findShipSet(recordList):
    shipSet = set()
    for record in recordList:
        shipSet.add(record ['Customer'])
    return shipSet

def findShipDowntimes(shipSet, recordList):
    downtimeMap = dict()
    for ship in shipSet:
        listOfDates = []
        for record in recordList:
            if record ['Customer'] == ship:
                listOfDates.append((record ['Start'],record ['End']))
        downtimeMap [ship] = sorted(listOfDates, key=lambda dateTuple: dateTuple [0])
    return downtimeMap

def overlap(dateTuple1, dateTuple2):
    if (dateTuple1[0] <= dateTuple2[0] <= dateTuple1[1]): # start2 in [start1, end1]
        return True
    elif (dateTuple1[0] <= dateTuple2[1] <= dateTuple1[1]): # end2 in [start1, end1]
        return True
    elif (dateTuple2[0] <= dateTuple1[0] <= dateTuple2[1]): # start1 in [start2, end2]
        return True
    elif (dateTuple2[0] <= dateTuple1[1] <= dateTuple2[1]): # end1 in [start2, end2]
        return True
    return False

def mergeDates(dateTuple1, dateTuple2):
    newStart = min(dateTuple1[0], dateTuple2[0])
    newEnd = max(dateTuple1[1], dateTuple2[1])
    return (newStart, newEnd)

def aggregateOverlappingDowntime(shipDowntimeMap):
```

```
    cleanedMap = dict()
    for ship, listOfDates in shipDowntimeMap.items():
        cleanedListOfDates = []
        for dateTuple in listOfDates:
            if len(cleanedListOfDates) == 0:
                cleanedListOfDates.append(dateTuple)
            else:
                overlapFound = False
                for i in range(0, len(cleanedListOfDates)):
                    if overlap(dateTuple, cleanedListOfDates [i]):
                        cleanedListOfDates [i] = mergeDates(dateTuple, cleanedListOfDates [i])
                        overlapFound = True
                        break
                if not overlapFound:
                    cleanedListOfDates.append(dateTuple)
        cleanedMap [ship] = sorted(cleanedListOfDates, key=lambda dateTuple: dateTuple
[0])
    return cleanedMap

def shipSumamryStatSum(shipDowntimeMap):
    aggregatedMap = dict()
    for ship, listOfDates in shipDowntimeMap.items():
        numDays = 0
        for dateTuple in listOfDates:
            numDays += (dateTuple [1] - dateTuple [0]).days + 1
        aggregatedMap [ship] = numDays
    return aggregatedMap

def formatDate(d):
    return d.strftime('%Y-%m-%d')

def printDowntimeMapToFile(downtimeMap, filename):
    output = ''
    for ship in sorted(downtimeMap):
        output += ship + ',\n'
        for dateTuple in downtimeMap [ship]:
            output += formatDate(dateTuple [0])+' ,'+formatDate(dateTuple [1])+'\n'
        output += '\n'
    with open(filename, 'w') as file:
        file.write(output)

def printDowntimeSummaryMapToFile(downtimeSummaryMap, filename):
    output = ''
    for ship in sorted(downtimeSummaryMap):
        output += ship + ',' + str(downtimeSummaryMap [ship]) + '\n'
    with open(filename, 'w') as file:
```

```
        file.write(output)

def run(filterPart):
    recordListWSS = readWSSrecords(filterPart)
    shipSet = findShipSet(recordListWSS)
    shipDowntimeMap = findShipDowntimes(shipSet,recordListWSS)
    shipNoOverlappingDowntimeMap                                          =
aggregateOverlappingDowntime(shipDowntimeMap)
    actualDowntimeMap = shipSumamryStatSum(shipNoOverlappingDowntimeMap)
    worstCaseDowntimeMap = shipSumamryStatSum(shipDowntimeMap)
    if filterPart == None: filterPart = 'All'
    printDowntimeMapToFile(shipDowntimeMap, 'Results/ship down dates WSS no
overlap - '+filterPart+'.csv')
    printDowntimeMapToFile(shipNoOverlappingDowntimeMap,   'Results/ship   down
dates WSS - '+filterPart+'.csv')
    printDowntimeSummaryMapToFile(actualDowntimeMap, 'Results/ship down dates
WSS Actual Summary - '+filterPart+'.csv')
    printDowntimeSummaryMapToFile(worstCaseDowntimeMap,   'Results/ship   down
dates WSS Worst Summary - '+filterPart+'.csv')

run(None)
run('015582849')
run('015611967')
run('013833198')
run('014867071')
run('013264156')
```

# APPENDIX C THESIS EVOLUTION

This project has evolved over the course of time. Our original objectives were to complete a thesis with a two-fold purpose:

- Address real problems affecting the U.S. Navy
- Challenge ourselves to utilize skill obtained at Naval Postgraduate School (NPS) to analyze these problems.

In keeping with these objectives, we chose a topic that included modeling and simulation. During studies at Naval Postgraduate School, we took a Business Modeling and Analysis course with Professor Daniel Reich.

This course peaked the authors interest in modeling and a good rapport was built with Professor Reich, which led to the authors asking him to become the thesis advisor. The authors also had several classes with Professor Sullivan and were impressed with his research, which he presented during his classes.

During the same timeframe a U.S. Navy Admiral came to NPS and spoke to many professors, instructors and students of the business school. He mentioned that the fleet was experiencing problems with the life cycle support of the CIWS. After hearing that speech and conducting some initial research the authors settled on answering the following research question:

*How modeling and simulation can be used to improve the operational availability and life cycle support of the CIWS?*

During the initial research of this project, the authors found out the CIWS is supported utilizing an Availability-Based Sparing (RBS) Model. According to the Defense Acquisition University, Availability Based Sparing is:

> Availability-Based Sparing (RBS) is the practice of using advanced analytics to set spares levels and locations to maximize system availability. Availability-Based Sparing determines the inventory requirements for achievement of availability goals:
>
> What to stock: parts, components, sub-systems (multi-indenture)

> Where to stock: strategic distribution points (SDPs), forward distribution points (FDPs), and/or at operational-level distribution points (multi-echelon)
>
> Taken together, these make up a two-dimensional Multi-Indenture, Multi-Echelon—or "MIME" RBS
>
> Typically, the RBS model objective is to achieve availability (such as Operational Availability) at the least investment. (DAU, 2019)

The authors original objective was to seek an alternative to the RBS model and try and improve operational availability for the CIWS using another model. After speaking to personnel in the PEO office, WSS, and the Naval Sea Logistics Center (NSLC) to conduct a full RBS model is extremely complex and time consuming. Three graduate students with one modeling course do not possess the knowledge, experience or have the time to complete this research.

After learning a full RBS model or similar model was beyond their capability the authors then decided to scale down the research question. Analysis would be conducted and between five and ten CIWS parts would be selected, based on these parts being the ones that most affected Ao. After this parts identification stage in lieu of a full RBS only these parts would be modeled to try and improve availability. Working with personnel at WSS and NSWC those five parts were identified. These parts are discussed at length in the previous sections of this chapter.

The next step of the research was to work with Professor Javier Salmeron, of the NPS Operational Research (OR) Department to model these parts. Professor Salmeron was a key contributor to developing Navy Aviation RBS Model, NAVARM. This RBS model provides the same data analytics as the RBS used to support the CIWS.

After deliberation and discussion amongst the authors and their advisors it became apparent that the authors did not possess the skill set, experience, knowledge or time to model the top five parts affecting CIWS operational availability. At this point in the project it was decided the best course of action would be to conduct detailed data analysis with the extensive data that the authors possessed.

In order to conduct our data analyses, the three data sets referenced above needed to be filtered, merged, grouped, and / or and cross referenced. Given the magnitude of the original data was too large for manual analysis and cleaning, Professor Daniel Reich assisted the authors in writing a Python computer program to prepare the data for analysis. This program allowed the authors to eliminate data that was not applicable to the project, focus on the most relevant date and conduct analyses from that data. The source code of the program can be referenced in Appendix B.

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