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**Optimizing Phalanx Weapon System Life-Cycle Support**

**1 October 2004**

**by**

**Dr. Aruna Apte, Lecturer,  
Graduate School of Business & Public Policy**

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# Abstract

The Phalanx Close-In Weapon System, (CIWS), was built as a terminal defense against current and evolving anti-ship missiles and aircraft which penetrate outer fleet air defense envelopes. Phalanx has evolved since then. Lower operational availability, escalating costs, and inadequate funding have prompted researchers and the Phalanx Program Office to conduct studies to examine certain aspects of the system. A comprehensive study was needed to look at all aspects of the program that will gauge the status of the current conditions, analyze the cost structures, examine the initiatives in place, and suggest areas which need further investigation. The objective of this report is to identify the weapon system's problem areas, if any exist. This report evaluates the status of and suggests research studies for improvement of the life-cycle support of the Phalanx weapon system. Evaluation is completed by reviewing the literature, analyzing the data, and communicating with the persons knowledgeable with the system. Exploring the conflict in the system and identifying the underlying performance drivers is the important objective of this research study.

**Key Words:** Phalanx, optimization, operational availability, reliability metric, casualty reports, life cycle support.





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I am grateful to RADM Jim Greene and Dr. Keith Snider for providing me with this opportunity to do research in optimizing the life-cycle support of the Phalanx Weapon System. Additional thanks go to both of them for helping me understand the world of the Navy and weapon systems in general. Finally, I also want to thank Karey Shaffer for her constant support through this project, and Elisa Holvino for her help in word processing.





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# 1. Introduction

## 1.1 History

Phalanx Close-In Weapon System (CIWS) was built as a terminal defense against current and evolving anti-ship missiles and aircraft which penetrate outer fleet air defense envelopes. It is designed to defend against small, high-speed surface crafts, helicopters, and general purpose aircraft in open waters, coastal waters or in port [Dutton 2003].

CIWS, designed and built by Raytheon Corporation, is a fast-reaction, rapid-fire, computer-controlled system with radar and Gatling gun designed to engage Anti-Ship Missiles (ASM). It is equipped to search, provide detection, threat evaluation, target acquisition, tracking, firing, target destruction evaluation, automatic kill assessment, and cease-fire data to control train, elevation, and discharge of the weapon. Thus, CIWS is a complex device which engages in multiple functions often performed by separate and independent systems. Operational tests and evaluations were performed when CIWS was first installed on board USS Bigelow in 1977. The device exceeded maintenance and reliability specification at that time [Dutton PEO Document].

CIWS has evolved substantially since then. Since 1980, the original Block 0 has been improved multiple times. Changes include: Block 1 Baseline/L0 in 1988, Block 1 Baseline/L1 in 1991, Block 1 Baseline/L2 in 1992, Block 1A in 1996, and Block 1B in 1999 [RM&A Handbook 2004]. The Phalanx overhaul program then began to accept Block 0 mounts and replace them with improved Block 1 systems. Prior to this, in the early nineties, Naval Ordnance Station/Louisville (NOSL) began to perform a thorough Class A overhaul. Such an overhaul included a complete teardown, stripping, resurfacing, painting, and individual testing of the mounts. The reliability of the post-overhaul systems was as good as the benchmark of the Block 0 production systems and was greatly improved in comparison to the older systems. CIWS was upgraded as the requirements for such a weapon system evolved to meet emerging threats.



Due to the Base Realignment and Closure (BRAC) process, in 1995, NOSL Louisville depot was scheduled for closure. Instead, it was purchased by the state of Kentucky and leased to the primary contractor for the CIWS overhaul program. The total ownership cost statements [LeClaire 2003], the expenditure of funds [Chaparro 2003], and the funding history [CIWS Funding History PEO Document] of the CIWS system all suggest the costs for overhauls escalated, while sponsor funding for the program became erratic. The funding issues and the soaring costs forced the Class A overhauls to be replaced by Class B overhauls. Class B overhauls are substantially reduced in scope compared to Class A overhauls. They are also not preset procedures, but are flexible to the observed condition of the mounts.

The class B overhaul effort that started in 1999 and has been in fleet use for three years has not met expectations in service reliability [Dutton 2003] or cost. During the period 1998–2002, overall ownership cost increased 53%. From FY02 costs to the projected cost in FY03, costs increased 28% [Chaparro 2003]. However, funding during these years was not steadily increasing. Instead, the numbers were erratic: \$47.26M in 1999, \$21.76M in 2000, \$46.17M in 2001.

## 1.2 Literature Survey

Lower operational availability, escalating costs, and inadequate funding have prompted researchers and the Phalanx Program Office to conduct studies to examine the condition of the system. Electrical and mechanical problems have been examined; cost assessments—such as total ownership cost, overhaul cost, and spending patterns—have been addressed; likewise, some marginal analysis of the cost-versus-potential-benefits has also been performed.

In his analysis for the CIWS Overhaul Program, Mr. Dutton, of the Program Executive Office Integrated Weapon System (PEO IWS), describes the basics of the weapon system. The document includes the mission and the performance of the system, evolution of the system, the last twenty years of data on the fleet population, technical details, results, and reliability of the weapon system [Dutton PEO Document].



In his document [Current Fleet Phalanx Population PEO Document], the current fleet population is described in detail. In a CIWS business case [Dutton 2003], Mr. Dutton assesses the costs and potential benefits of various overhaul strategies intended to restore the CIWS system. This case study concludes that Class A overhauls provide the most favorably reliable improvements for the cost; the case also asserts the optimal interval for overhauls for service reliability is seven years. Michael R. Chaparro, in his MBA professional report at the Naval Postgraduate School (NPS), analyzes the spending patterns associated with the CIWS program [Chaparro 2003]. The acquisition plan for the weapon system for the next few years and the various initiatives (both in place and proposed) are explained in Dutton's 1995 document. This plan explains the need for, as well as the objective of, the program, the monetary, business, technical, and logistical considerations, and the plan of action for FY05 in production, procurement, and design.

The CIWS handbook [RM&A Handbook 2004] is also an invaluable resource for researchers. The definitions, metrics, and analysis of various fiscal and operative aspects described in the handbook were extremely helpful for the above reports. In addition, it provides valuable information on Reliability, Maintainability, and Availability (R, M, & A). The handbook is the single common source of information for the CIWS community. It identifies major issues and the corrective actions, funding shortfalls and their effects. It concludes by describing the initiatives currently in place to improve the Mean Time Between Failure (MTBF) for the CIWS system.

Other documents are vital to understanding the CIWS system and its fiscal repercussions. The information about CIWS's funding history is given in the CIWS Funding History PEO Document. The total ownership cost study, written by LCDR Jeff LeClaire of the Phalanx Programs Office, compares the cost structures of FY98 with FY02 and tracks the changes for FY03 [LeClaire 2003]. In addition to the sources mentioned previously, several more records were reviewed to gain background information about Naval Warfare Systems in general and CIWS in particular: Cela 1994, Guzman, Carlos and Gaffe 1995, Oxendine and Hoffman 2002, Steele 1998.



### 1.3 Motivation

All the literature reviewed addresses certain aspects of the CIWS weapon program. A comprehensive study was needed to examine all aspects of the program, gauge the status of current conditions, analyze the cost structures, identify the initiatives in place, and suggest areas which need further investigation. This study set out to do just those things. The goal of the report is to provide recommendations to optimize the Life-support Cycle of the Phalanx Weapon System. The objective of this report is to identify, if any exist, problem areas for the weapon system. This report evaluates the status of and suggests research studies for improvement of the life-cycle support of the Phalanx weapon system. Evaluation is done by reviewing the literature, analyzing the data, and communicating with the persons well-informed about the system. Exploring the conflicts in the system and identifying the underlying performance drivers is the critical objective.

After reviewing and analyzing some of the above-mentioned literature, and discussing the program history with knowledgeable persons, the researcher found the financial and operational problems became evident. The primary reason for the financial difficulty is the uncertainty of funding. But this uncertainty may be alleviated if initiatives are in place for optimally allocating the given funds. Lack of funding leads to operational constraints. Misguided strategy, untrained personnel, and/or system operators misinformed about the root cause also lead to operational issues. Due to the complexity, the size, the maturity, and the diversity of the CIWS system, no single measure can correct any of the problems that exist.

This report is arranged as follows. In the second section, the report gives the overview of the status of the weapon system. Then, it discusses the performance drivers of the financial and operational issues and describes their interrelationship. In the third section, the report suggests recommendations on how to improve the system utilizing initiatives that are already in place and by conducting further investigations. Here, the report describes the tools available to be used as probes and also proposes the research necessary to help certain facets of the program. The report concludes in





the fourth section by stating specific research studies recommended for CIWS in the future. The fifth section lists the referenced documentation.

## 2. Anatomy of the System

### 2.1 Overview

The CIWS is a complex, mature, large, and diverse weapon system. Phalanx is designed to search, detect, and evaluate threats, acquire target, track, fire, and evaluate target destruction, provide automatic kill assessment, and process the data. Any system this complex has numerous interdependencies which are, by their very nature, difficult to analyze. Scrutinizing every area concurrently is not easily done. At the same time, analyzing just one aspect provides a skewed picture. It is possible to look at the bigger picture; yet, this solution may mask the depth of the problem and, therefore, the actual cause. Secondly, the maturity of the system exacerbates the problem since the last minute “band-aid” solutions over the years have never solved the real issues. The traditional procedures, though outdated, are hard to change due to resistance and lack of expertise. Thirdly, the large population of the system magnifies the small increase in cost to large proportions across the system. Finally, the diversity of the system (due to different baselines) creates unique status of the mounts. This in turn creates unique problems. Currently, CIWS has 158 ships, 308 mounts, and 6 baselines. The different baselines for all these mounts necessitate increased logistical complexity to provide necessary spares; this complexity likewise causes increased lack of availability of the maintenance expertise on the ship, and places a heavy burden on inventory managers to carry the required spare parts.

However, this interdependent complexity also suggests that solving one problem will help cure many of the difficulties caused by the root problem. Thus, probing deeper and investigating further to isolate such a problem is worth the time and resources. The maturity of the system suggests such data is available. After collecting and assembling data from the various activities linked to the system, gaining better understanding of the



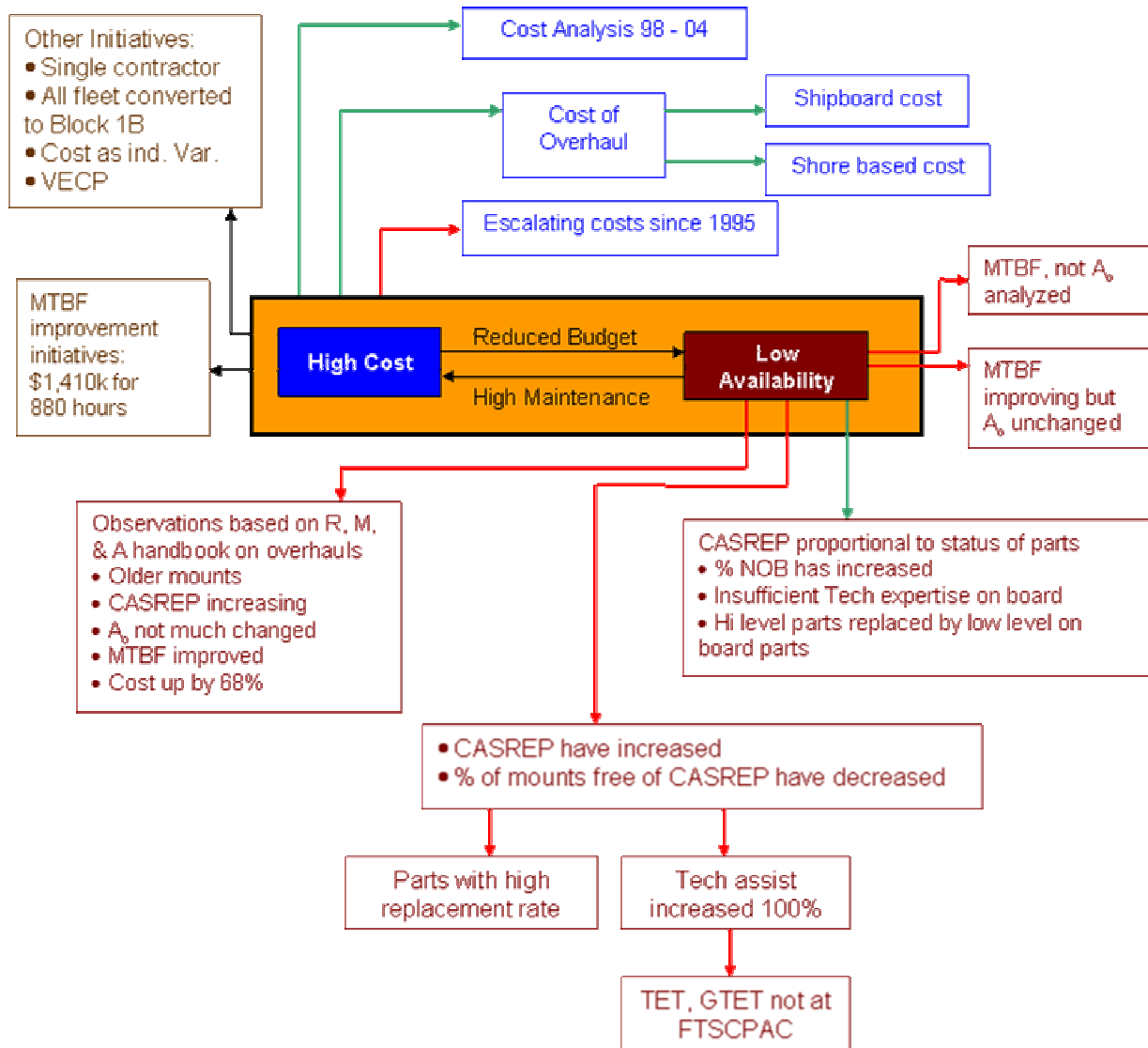
structure may be possible. Though the large population of the system magnifies small cost increases, it also suggests that small savings will result in large cost reductions. While the issue of multiple baselines is currently being addressed, this problem will not be solved until all the mounts are brought to the same standard.

The CIWS, based on the literature reviewed, data analyzed so far, and communication with PEO IWS personnel, seems to be caught in a vicious circle of high cost and low availability. Low availability leads to high-cost maintenance, which leads to higher costs, which in turn prompts budget cuts, all of which result in further reduction in operational availability. This downward spiral has been going on for at least the last ten years. Likewise, the lack of funds reduces the preventive maintenance budget, which lowers availability, which forces high-cost corrective maintenance. This clearly escalates the costs. This is a commonly observed problem with many systems. The CIWS, as noted earlier, is a complex, mature, and high-population weapon system with diverse baselines; therefore, the problem is more pronounced in relation to it than in some other systems. To analyze this cyclical syndrome, the CIWS was mapped into a hypergraph of observations that needs further analysis and investigation. Figure 1 shows this mapped hypergraph. Subsets of this hypergraph will be analyzed in succeeding paragraphs.

At the center is the “high-cost/low-availability” syndrome. Green arrows lead to the observations that need more specific analysis. Red arrows suggest more in-depth investigations of the current status. Black arrows point out the initiatives in place. The following subsections discuss the influential factors and performance drivers for this syndrome and are illustrated using sub-hypergraphs of the graph in Figure 1 (labeled Figure 1.a, etc.).



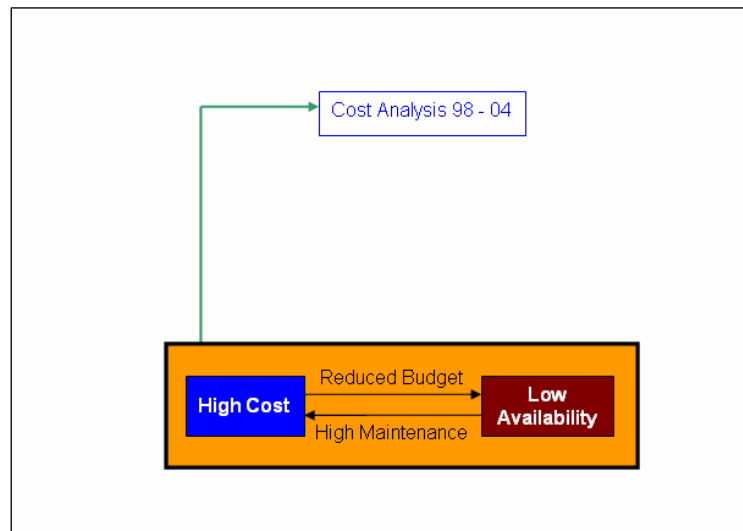
Figure 1: Hypergraph of Interdependencies



## 2.2 Performance Drivers

### 2.2.1 Cost Analysis

Figure 1.a: Sub-hypergraph for Cost Analysis



Preliminary analysis of Total Ownership Cost (TOC) based on both Chaparro and LeClaire's research led to Tables 1, 2, and 3. These tables compare the costs of the In-Service Engineering Agent (ISEA), the Naval Inventory Control Point (NAVICP), and an Original Equipment Manufacturer (OEM) Depot. These costs are analyzed based on the premise that operational availability,  $A_o$ , is driven by Mean Logistic Delay Time (MLDT), which in turn is driven by Mean Supply Response Time (MSRT), and Mean Outside Assistance Delay Time (MOADT). The functional entities contributing to MSRT and MOADT are the ISEA, NAVICP, and OEM Depot.

Based on Naval Sea Systems Command (NAVSEA) data, Table 1, the cost for ISEA activities increased 7% from FY98 to FY02. The projected cost for FY03 indicated a rise of 40.5% in one year. NAVICP cost increased a whopping 299% from FY98 to FY02, whereas the projected cost increase for FY03 only rose by 28.8%. Similar increases are observed for the OEM Depot: 269.1% from FY98 to FY02 and 23.1% for projected FY03. Review of Chaparro's 2003 research showed similar increases; these are summarized in Table 2. Costs from both sources are compared in Table 3. They



point to a similar trend: large increases from FY98 to FY02 but slightly lower increases for projected FY03. The only discrepancy between the two sources is for the NAVICP data.

Table 1: Observations based on NAVSEA Total Ownership Cost Data

Department	Change from FY 98 to FY 02	Change from FY 02 to projected FY 03
ISEA	+ 7%	+ 40.5%
NAVICP	+ 299%	+ 28.8%
OEM Depot	+ 269.1%	+ 23.1%

Table 2: Observations based on Total Ownership Cost Data from Chaparro 2003

Department	Change from FY 98 to FY 02	Change from FY 02 to projected FY 03
ISEA	+ 12%	+ 42.6%
NAVICP	+ 39.9%	+ 23.8%
OEM Depot	+ 286%	+ 23.6%

Table 3: Comparison between TOC of NAVSEA and Data from Cela 2004

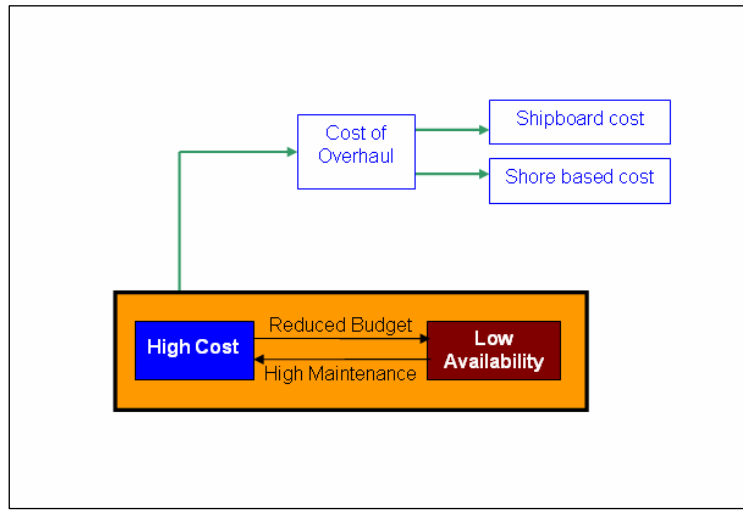
Department	Change from FY 98 to FY 02		Change from FY 02 to projected FY 03	
	NAVSEA	[Chaparro 2003]	NAVSEA	[Chaparro 2003]
ISEA	+ 7%	+ 12%	+ 40.5%	+ 42.6%
NAVICP	+ 299%	+ 39.9%	+ 28.8%	+ 23.8%
OEM Depot	+ 269.1%	+ 286%	+ 23.1%	+ 23.6%

In addition to the total ownership costs described in tables 1 – 3, the categorized costs in Chaparro’s 2003 document convey that the government material cost decreased from FY98 to FY02 and was to increase 371% in projected FY03. The contractor material numbers and travel costs from FY98 to FY02 are not available, but they rose an amazing 1046% from FY02 to projected FY03. These increases in costs are clearly abnormal compared to the rest of the departments and categories.



## 2.2.2 Cost of Overhauls

Figure 1.b: Sub-hypergraph for Cost of Overhauls

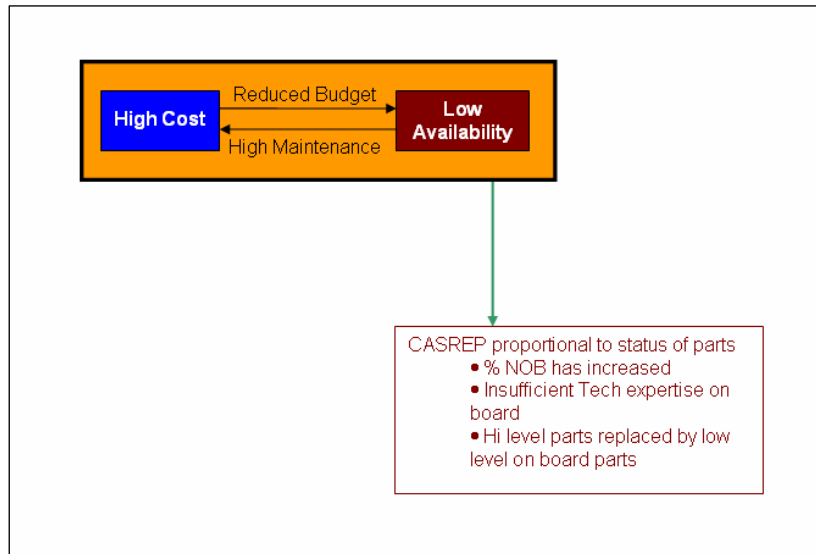


Phalanx mounts have parts that are ‘limited life’ parts. Therefore, as the mounts are maintained, these parts have to be replaced. Class A overhauls include complete replacement of each of these parts during the conversion of the mounts to Block 1B. For this reason, Class A overhauls are more expensive than Class B overhauls. Class B overhauls conduct maintenance based on the condition of the part. If a part seems in satisfactory condition, it is not replaced. It often happens that this part is at the end of its lifecycle. Then, when a “newly” overhauled mount is used, the part fails, thus reducing the operational availability. Therefore, though more expensive than Class B overhauls, Class A overhauls are generally justified.

The Class A overhauls are performed as follows: older mounts are worked on at the depot in a production line. The parts are stripped, cleaned, painted, etc. It takes about two years to completely process the mounts. Depending on the ship’s availability, these overhauled mounts are installed on a ship that can be spared for the installation. However, it is important to note that mounts removed from one ship are not necessarily reinstalled on the same ship.

### 2.2.3 Casualty Reports and Parts on Board

Figure 1.c: Sub-hypergraph for CASREP and Parts on Board

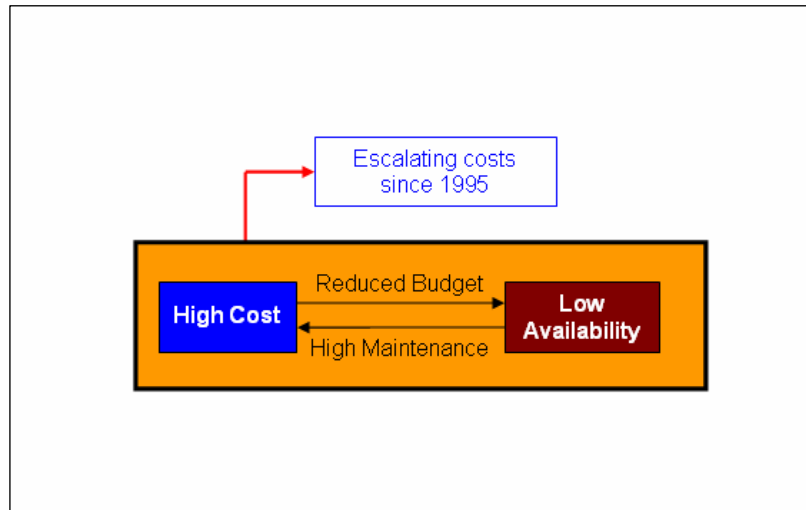


There is a clear relation between casualty reports (CASREPs) and the status of parts needed [RM&A Handbook 2004]. A critical fact is that the parts that cause CASREPs are mostly the problem parts which are replaced in Class A overhauls.

The causes behind these effects need extra analysis. Some of the factors included in this domino effect are: an increase in the percentage of not-on-board (NOB) parts, and high-quality parts replaced by on-board low-quality parts [RM&A Handbook 2004]. Along the same lines, multiple CASREPs caused by the same class of defective parts have multiple causes-and-effects. Defective parts have to be replaced. They have to be replaced by parts available on board. Sometimes the available parts are of lower grade. This leads to more and frequent CASREPs. Using low grade on board repair parts (OBRP) will cause this cycle of broken-replace-broken to continue. CASREPs will increase. And, though the days to casualty-corrected reports (CASCOR) will decrease, that seemingly-quick reaction time will not improve the reliability of the system, since the same problem parts will cause the same malfunctions.

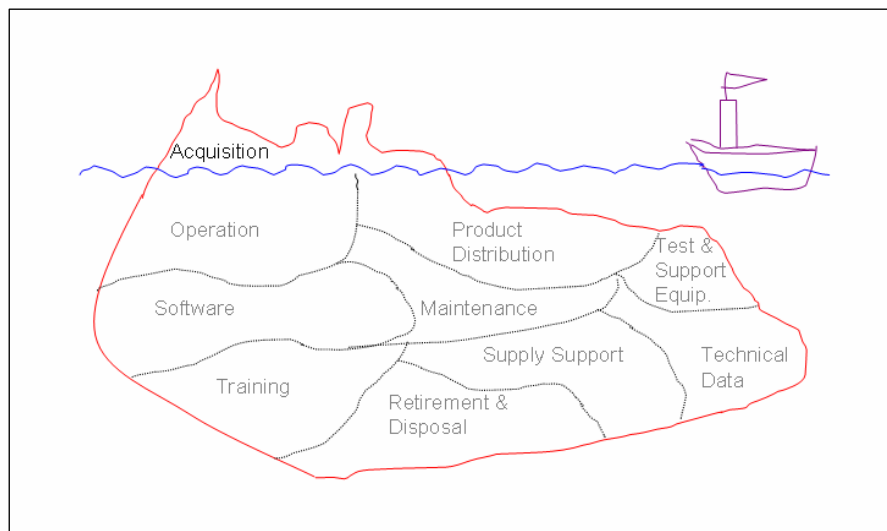
## 2.2.4 Escalating Costs

Figure 1.d: Sub-hypergraph for Escalating Costs



The total cost visibility of a system is often compared with an iceberg [Blanchard 6<sup>th</sup> Edition]. When a system is acquired, in addition to the acquisition cost, the cost of logistics for life-cycle support should be considered from the beginning and not after-the-fact. Figure 2 shows various hidden costs. To name just a few, these costs are operation, maintenance, supply support, and training costs.

Figure 2: Total Cost Visibility

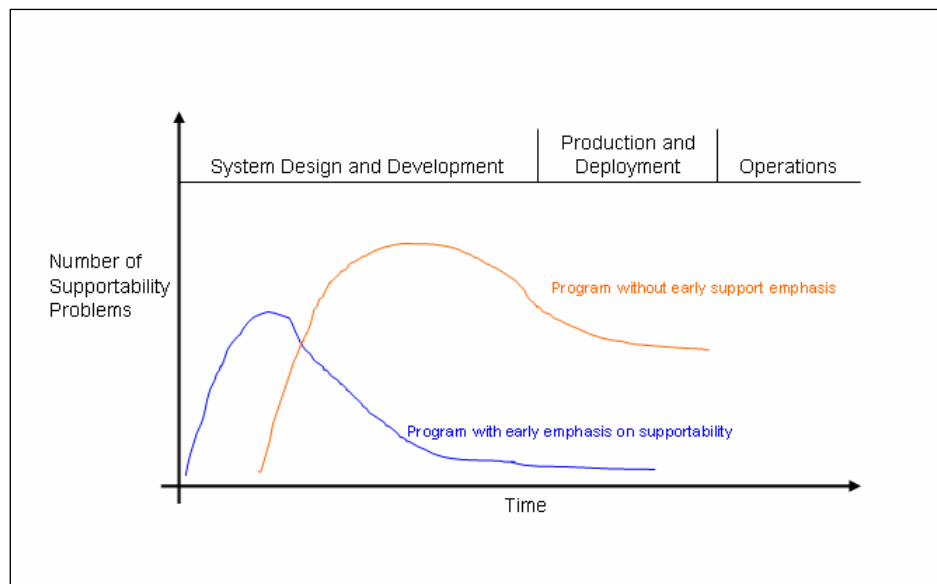




If these costs are not considered for the system at the beginning, the maintenance takes a back seat due to lack of funding. Marginal maintenance then leads to supportability issues.

Figure 3 depicts this issue for both a system with early emphasis on supportability and for a system without this feature [Blanchard 6<sup>th</sup> Edition]. As systems mature, the supportability costs start gaining magnitude. Following this same trend, after almost twenty years since installation, costs of Class A overhauls for CIWS started to escalate starting in 1995 [Dutton 2003 and 1995].

Figure 3: Comparison of Programs with and without Supportability

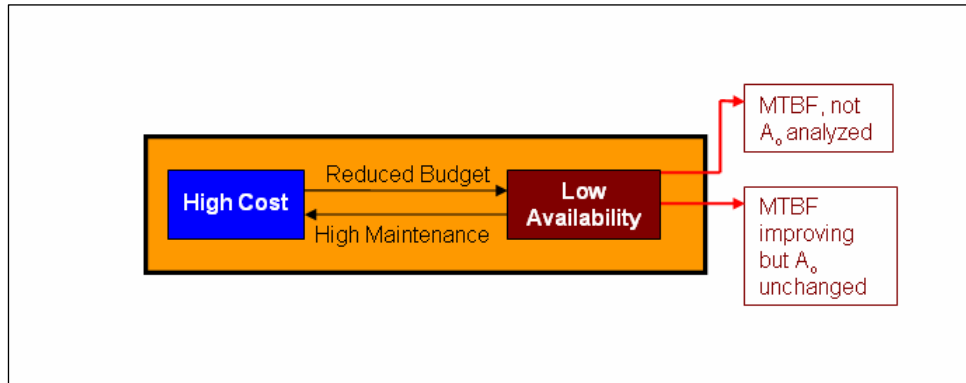


After the initial installation, the CIWS began to be upgraded as the needs of the Navy and defense strategy of the government changed. The Block 1 upgrades were completed at NOSL. As stated previously, in 1995, under the BRAC process, NOSL was selected to close. However, the facility was purchased by the state of Kentucky and leased to the primary contractor to continue the overhaul program. Perhaps due to the depot transition, or to reasons that need additional investigation, the costs for overhauls escalated immediately. Such high cost normally leads to reduction in funding, which leads to substantial cuts in maintenance. Based on the literature reviewed, the

increased cost for Class A overhauls resulted in a decision to downgrade to Class B overhauls

## 2.2.5 The Reliability Metric

Figure 1.e: Sub-hypergraph for The Reliability Metric



The reliability literature [Blanchard 6<sup>th</sup> Edition] and the Military Handbook for Operational Reliability [Operational Availability Handbook OPNAVINST] define  $A_o$ , operational availability, as the quotient of “up time” over “total time.” This equation is the performance measurement of a system.

$$A_o = \frac{MTBF}{MTBF + MTTR + MLDT}$$

### Equation 1. Performance Measurement of a System

MTBF is the mean time between failures. MTTR is mean time to repair, which can be further explained as “time it takes to remove interference, remove, replace, and test the failed component, return the equipment to its original condition, and replace and retest any system interference removed to get to the failed equipment.” MLDT, or mean logistic delay time, is the cumulative time required by all logistics processes to support the requisite repair.

The reviewed literature about the CIWS suggests that MTBF has been thoroughly analyzed. The comparison of MTBF across the weapon systems and MTBF

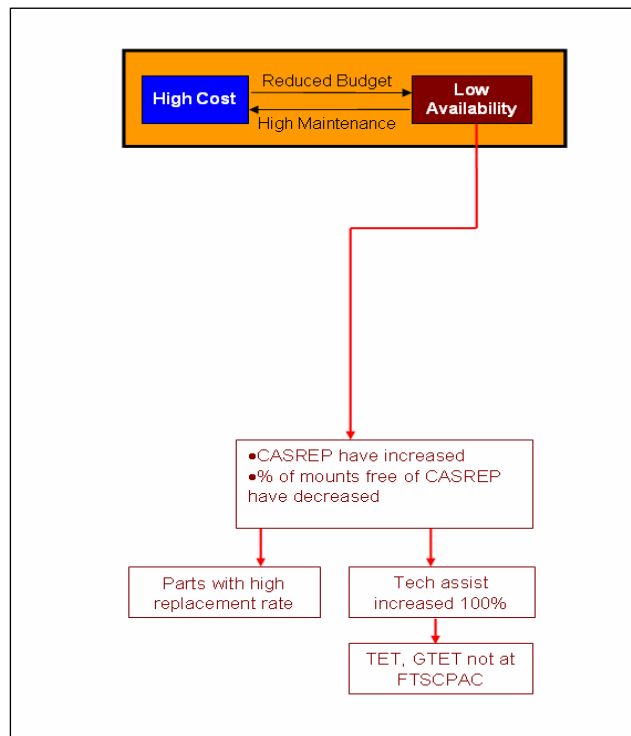
vs. the age of the system is well documented. The initiatives for improving MTBF are also in place. As upgrades for CIWS have been introduced, MTBF has increased [Dutton 2003, RM&A Handbook]. As Table 4 suggests, the Phalanx MTBF (in other words, the system's reliability) has significantly increased; however, MLDT also has increased. These combinations result in a fairly constant  $A_o$  trend [RM&A Handbook 2004]. Program manager demand factors (PMDF), metrics for anti-air warfare (AAW) and anti-surface warfare (ASUW), compared over FY01–FY03 are given in Table 4.

Table 4: Comparison of MTBF and MLDT for AAW and ASUW

	AAW				ASUW		
	01	02	03		01	02	03
<b><math>A_o</math></b>	0.75	0.65	0.81		0.74	0.69	0.72
<b>MTBF</b>	561	649	795		693	622	549
<b>MLDT</b>	136	220	142		122	150	174

## 2.2.6 Casualty Reports

Figure 1.f: Sub-hypergraph for Casualty Reports

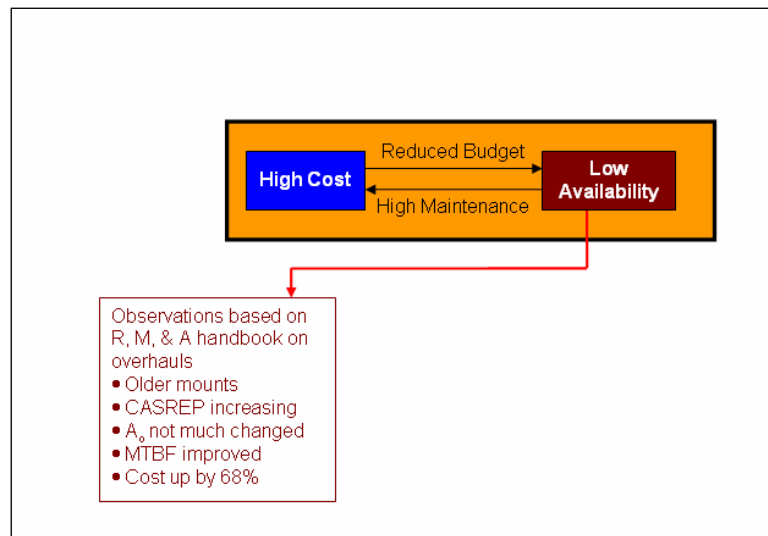


The data for CIWS suggests that over the last 6-7 years, the number of CASREPs has increased by at least 5% [RM&A Handbook 2004]. The increase in CASREPs, as discussed previously, is proportional to the status of the parts, working and spare, and status of the inventory. But, in 2003, the percentage of mounts that were CASREP-free dropped from 95% to 90%. So, not only are there more CASREPs, but they are distributed across the fleet. Unfortunately, the problem of malfunction is not concentrated on a few ships.

If there is insufficient expertise on board for the diagnosis of a malfunction or for replacing the part to correct the malfunction, CASREPs across the fleet will increase greatly. It is critical to note that, based on the data available, technical assistance requests have indeed increased [RM&A Handbook 20046]. In fact, the tech assist requests were about 0.3/system/year in 1997, and in 2003 were at least 0.95/system/year. That is an increase of more than 300%. Supplementary investigation of the possible cause is clearly required.

## 2.2.7 The Overhauls

Figure 1.g: Sub-hypergraph for the Overhauls



The correlation between CASREPs and the age of the mounts, though intuitive, is validated by data. Specifically, 71% CIWS mounts are 6 years or older. After the overhaul, CASREPs increase with time—thus, the older the mounts, the greater the

increase in required overhauls. Hence, the more the time passes since overhaul, the more CASREPs occur. As more years pass after overhaul, costs escalate further. It should also be noted that  $A_o$  one year after the overhaul was 0.77, whereas 10 years after overhaul, it was 0.70. Therefore,  $A_o$  has decreased 10% in ten years. This fact must be put in context against the benchmark. But, there is no benchmark available for  $A_o$ . The decrease in  $A_o$  over 10 years, though explainable, should be studied for its impact on readiness. If the value of  $A_o$  immediately after overhaul could have been higher, then a drop of 10% in its value could have been sustainable and possibly acceptable in terms of readiness.

MTBF, in the first year after overhaul, was 500. Yet, after ten years it is 350 [RM&A Handbook 2004]. But, if MTBF is tracked using PMDF, then MTBF has increased from 450 in 1999 to 692 in 2003. MTBF also has increased from 561 in 2001 to 795 in 2003 for AAW. In the case of ASUW, numbers have dropped from 693 to 549. All these different values of MTBF need to be put into perspective and analyzed for their actual impact on fleet readiness.

### 3. The Cure

#### 3.1 Analysis of Influential Factors

##### 3.1.1 The Costs

Various costs associated with CIWS need to be analyzed further to clarify their correlation with increases in overall costs over the years. The ownership costs were recorded for FY98, FY02, and FY03. These are too few data points to project any trend. However, some patterns can be identified, and they lead to the following observations.

The overhaul strategies for restoring Phalanx to original condition and to sustain life-cycle support suggest the cost-benefit analysis of such overhauls needs further examination. Though the marginal cost analysis for different overhauls (Class A, Class B, Class B + R & M ECPs, and Class B +CCAs + R & M ECPs) is recorded in detail in Dutton's 2003 report, analysis of the shipboard and shore-based costs of the same



would be beneficial as well. Supplemental study of the escalating costs since 1995 is vital. Were these increases due to outsourcing? Or did the inherent cost go up? Or, did the way costs were accounted for change? The answers to these questions can lead to reduction in cost. Along the same lines, there may be valuable lessons related to outsourcing here.

### 3.1.2 The Reliability Metric

The reliability literature dictates that improving MTBF does not necessarily improve  $A_o$ . Recall Equation 1:

$$A_o = \frac{MTBF}{MTBF + MTTR + MLDT}$$

MTBF appears in the numerator as well as in the denominator. So, changes in MTBF do not affect  $A_o$  necessarily. In that case, it may be preferable to analyze  $A_o$  instead of MTBF. Therefore, the choice of the reliability metric used needs to be investigated. It is important to note that there exists no specification for minimum  $A_o$  in Department of Defense (DoD) guidelines. Yet,  $A_o$  should be one of the Key Performance Parameters (KPP) [Boudreau et al 2003]. Without such performance measures in place, improving  $A_o$  is a futile endeavor.

Equation 1 also includes MTTR in the denominator. This variable is normally a small number, so it does not influence  $A_o$  as much as other factors. This leaves mean logistic delay time (MLDT) to be the mathematical driver of Equation 1. MLDT includes Mean Supply Response Time (MSRT), Mean Administration Delay Time (MADT), and Mean Outside Assistance Delay Time (MOADT). Analysis so far suggests that MSRT, due to transportation from within and off the ship, especially with high percentage of NOBs and MOADT due to lack of expertise on board, have larger values. Therefore, to improve  $A_o$ , MLDT (and, consequently, MSRT and MOADT) should be improved.

For example: consider an electronic system that has a certain component failing 1000 times per million hours, or, in other words, MTBF is 1000 hours. MTTR is usually a



small number for electronic systems, say, 3 hours in this case. MLDT, on the other hand, is measured in terms of days or weeks. Let MLDT be 3000 hours. This, by Equation 1, yields  $A_o$  to be 0.25. Keeping everything else the same, but introducing a significant improvement in reliability, say a 30% increase in MTBF, yields  $A_o$  to be 0.30. This is a 0.05 increase in operational availability which will go unnoticed in spite of a huge increase of reliability, because the supportability factors of the system remained the same. Therefore, once the system is fielded, increasing effectiveness of the logistics support pipeline is more effective for  $A_o$  than for the system reliability. As this example suggests, investigation of MSRT for the Phalanx system will uncover various issues leading to NOB parts increase in number of CASREPs, and CASCOR.

The hypothesis that MSRT and MOADT are the drivers for MLDT, which in turn drives  $A_o$ , has to be tested and validated—especially if the costs associated with MSRT and MOADT are increasing; it is crucial these be researched further. The costs such as ISEA costs for systems, acquisition, engineering support, CIWS I & C spares, ordnance alteration (ORDALT), acquisition support, fleet modernization program (FMP) support, NAVICP support, performance based logistics (PBL), costs for defense logistic agency (DLA) procurement, storage and distribution of spare parts, and OEM Depot costs all need to be studied. As the system gets more mature, the deterioration of the mounts will progress. On the other hand, as years go by, acquired experience of the system should decrease MSRT and MOADT. Therefore, this aspect of  $A_o$  also needs specific attention.

Some initiatives are in place for improving MTBF. Table 5 shows these initiatives, the cost for their improvement, the amount of improvement in MTBF, and the marginal cost per hour of improvement.



Table 5: MTBF Improvement Initiatives

Initiatives	Cost in Thousands	Improvement in MTBF
Class A Overhauls	\$700	400 Hours
Back Fit	\$30	23 Hours
SEARAM Shipboard rolling airframe missiles	\$500	129 Hours
Dual Use Hardware		
CCA Circuit card assembly	\$72 (Total Saving Across the Fleet \$752)	23 Hours
Gun and Ammo Handling	\$100	100 Hours
Surface TV Camera	\$60	133 Hours

### 3.1.3 Issues Driving CASREPs

The evident correlation between CASREPs and certain parts in the mounts needs to be addressed. 80% of the problems are caused by 20% of the parts. The Class A overhauls replaces this 20% of the parts 100% of the time. In order to cut costs, replacing these with low-quality parts already on board will clearly increase the CASREPs. This occurrence needs additional investigation. Likewise, the correlation between CASREPs and Class A overhauls needs more data.

Researching the status of the system at a broader level suggests two causes for the increase in CASREPs. One is the high replacement rate of certain parts. The other is the increase in tech assists. The high replacement rate of the parts should be studied further with the “five whys” procedure of the cause-and-effect analysis. The quality of the spares, availability of the appropriate spares, and frequency of maintenance—all these things may be causes. Pareto Analysis will assist in finding the top CASREPs requisitions as documented in the RM&A Handbook 2004. The supply support factors for the reliability of any system are reliability of the item to be spared, quantity of items used, probability that a spare will be available when needed, criticality of item application with respect to mission success and, of course, cost. All these factors need a second look [Blanchard 6<sup>th</sup> Edition].





CASREPs occur not only because mounts are older. They also occur when there are no personnel trained for the technology available on the ship with the newly installed mounts. This necessitates personnel training before the ship is deployed. There are various year-round online enhancement training courses available. Such training is a prerequisite for reducing the number of CASREPs. Lack of expertise on ships suggests that personnel are not trained for the on-board maintenance or support of the overhauled mounts. This deficiency may be due to the fact that maintenance is outsourced. Current DoD trends about outsourcing are discussed further in 3.2.5. If the maintenance and support for certain overhauls are outsourced, then the need for expertise on board may be deemed redundant and hence cut from funding. This reduced budgeting may result in the system itself bearing an unexpected burden due to unanticipated corrective maintenance especially during the first two years after Class B overhauls. An initiative for training improvement is in place. Technician enhancement training, TET, and gun technician enhancement training, GTET, are being conducted by Fleet Training and Support Center Atlantic (FTSCLANT). If TET and GTET have reduced the off-board tech assists, those reductions need to be substantiated.

## 3.2 The Toolkit

### 3.2.1 Theory of Constraints

Clearly there exist conflicts originating from factors such as complexity, maturity, magnitude, and diversity of system baselines for the Phalanx CIWS. But, these constraints can be exploited to the advantage of the system. The Theory of Constraints suggests that in the presence of constraints, one should first identify the system constraints [Goldrat 2<sup>nd</sup> edition]. Next, one should decide how to exploit them. Thirdly, one should subordinate everything else to this decision. Lastly, removing the system constraints could solve the problem. If a constraint gets violated in any one of these steps, one should not let the inertia become another system constraint, but should go back and rectify the situation.



### **3.2.2 Total Quality Management**

Total quality management (TQM) can be used in order to further isolate the possible problem areas and gain insight into them. In TQM, statistical process control (SPC) is commonly used for problem solving and continuous improvement. These tools are not substitutes for the judgment and the process expertise of the personnel. But, they help deal with the complexity of the system and turn raw data into applicable information. The SPC tools useful for analyzing and investigating the CIWS could be Pareto Analysis, Data Collection, and Cause-and-Effect Diagrams, to name a few [Apte 2004].

### **3.2.3 Pareto Analysis**

Pareto Analysis is a systematic approach for identifying, ranking, and working to permanently eliminate problems. It focuses on important error sources. The 80/20 rule of this analysis, 80% of the problems are due to 20% of the causes, is frequently true with systems. The analysis is based on the premise that usually a small number of faults cause the majority of malfunctions. So, it helps to separate the vital few and trivial many. The recording of the data for Pareto Analysis is a useful exercise for understanding process characteristics. This analysis is also useful in vendor evaluations. To perform Pareto Analysis, first the classification of defect/problems to be monitored needs to be defined. The period of time over which assessment is to be made needs to be defined. After accumulating the frequency of occurrences of each class of defects/problems over the period, a histogram is drawn in the descending order of frequency of occurrences. This identifies the classes that constitute the majority of defect/problem occurrences. Data collection and analysis strategies need to be settled upon at the offset. There needs to be agreement and clear reason for any data collection. The questions that might be asked are Why? What? Where? How much? When? How? Who? How long?

### **3.2.4 Cause-and-Effect Analysis**

The Cause-and-Effect diagram is sometimes known as the fish-bone diagram or Ishikawa diagram. Pareto analysis identifies the key problems and symptoms; yet, the



cause-and effect diagram is also used to sort out the causes of the problem. Brainstorming sessions of groups of personnel involved is required. These sessions help identify complete lists of causes of the problem, and the relationship between causes and effects in a rational manner. The process of doing this educates everyone involved in the system regarding the causes and effects of the problem.

### **3.2.5 Outsourcing**

The literature and current research in outsourcing indicates that outsourcing products, not service, is more advantageous to most systems. Outsourcing of the maintenance of a weapon system reduces the need for training of ship board personnel in certain maintenance procedures. This may lead to a reduction in the  $A_o$  of a weapons system due to importing outside maintenance expertise when systems go down. Yet, the in-sourcing of certain services is crucial to the health of critical weapon systems. This was true in the past and is especially true here since the service involves a last-ditch defense system. However, this approach may not be efficient and fiscally responsible in lieu of the current trends in DoD. As noted by Commander, U.S. Fleet Forces Command, Adm. William J. Fallon, “We can and will continue to exercise fiscal discipline in achieving combat readiness by undertaking a fundamental change in culture, one that incorporates a continual, rigorous evaluation of the costs in preparing for combat, and the assumptions that drive those costs” (Story Number NNS041001-09 [www.news.navy.mil](http://www.news.navy.mil)). This initiative suggests that outsourcing of services—if it provides supportability at a reduced cost—needs to be researched further.

### **3.2.6 Optimization**

Optimization is a tool that prescribes the “best” possible action to take under the assumptions of a formulated model. The model consists of a set of expressions allocating scarce resources among competing activities. Usually assumptions made for optimization models are severe compared to the ones existing in the real world. But, this is a powerful tool when a limited quantity of economic resources, such as labor, time, raw material and (most importantly) funds, are to be allocated. There may be more than one way to disperse the resources; or, if the resources are too scarce, there may be no



feasible solution. Each activity yields a return based on the set objectives. The solutions found, if any, can be subjected to “what if” analysis for the robustness of the data used. A typical mathematical model in optimization has a stated objective that is either to be maximized or minimized subject to the constraints caused by limitations. The solution to the model prescribes the optimal plan of action and rewards gained if this plan is implemented.

### 3.3 Current Directions

Data provided by, and communication with the Naval Seas System Command (NSSC) asserts that, until this year, there was a backlog for mount conversions to Block 1B through Class A overhauls. The number of mounts overhauled was 5-6 per year. Yet, some research asserts the mounts need to be changed every 7 years to optimize their functionality [CIWS Funding History PEO Document]. This translates to about 40 mounts per year. Due to lack of funding, less than 40 mounts per year were overhauled, and therefore, the level of maintenance decreased greatly. However, the importance and necessity of CIWS has been recognized. CIWS does what it was intended to do. The CIWS Block 1B system is particularly effective in surface mode. As far as leakers (missiles that can penetrate the outer AAW/ASUW shield) are concerned, CIWS is considered the terminal defense. Though this has been the case for many years, appreciation for systems such as CIWS has been enhanced as the terrorist threat, as epitomized by the USS Cole, has emerged. The program now appears to have the congressional and other support necessary to improve system A<sub>o</sub>. The current program funding allows the remaining 267 mounts to be converted to Block 1B through Class A overhauls. By FY10 CIWS is projected to “get well.” It will no longer be on “life-support,” and the average age of the mounts will decrease over the years.

Valued Engineering Change Proposals (VECP) are incentive methods in production processes in which the producer modifies the existing process to improve efficiency and cost. This is done in consultation with the client so the benefits can be enjoyed by both parties: the client and the contractor. In the past, the contracting environment used to be very rigid about the change in specifications or production



processes. This new emphasis on collaboration has added to the flexibility of manufacturing and serviceability. Various VECs are in place and will be in production in FY05-06. During the process of Class A overhauls, these VECs enhance the mounts at reduced cost. The OEM researches and develops enhancements (at no cost to the CIWS program) and implements the changes, upon approval, during production. The benefits, both of enhancement and savings, are shared.

The CIWS program office requested that the Naval Warfare Support Center, Corona (NWSC/Corona) perform an independent logistic assessment (ILA) for CIWS. The report was produced in July 2004 but there are certain amendments still under consideration. This report will be available in October 2004 and should shed more light on future directions for CIWS.

The current initiatives, such as implementation of Class A overhauls, funding for installation of Block 1B mounts, improvement of MTBF, and independent logistic assessment are steps in the right direction. But as the hypergraph (Figure 1) describes, the scope of CIWS supportability is broad. To ensure that the system functions and delivers economically what it is designed and intended to deliver and uses the funds assigned in an optimal way, various studies are needed. The tools for these investigations may be derived from various subject areas. These subject areas were explained in the previous section. Yet, some of the necessary research studies using these concepts are described in the next section.



## 4. Conclusion

### 4.1 Future Research

The analysis so far has arrived at the following hypothesis. The high cost of maintenance of CIWS, increase in CASREPs and tech assists leading to reduction of reliability, initiatives to increase and actual increases in MTBF, and unchanged  $A_0$  in spite of improved MTBF are all effects of causes that need added investigation. In fact, all the stated effects could form titles of research projects. The research studies that will be of importance to the life-cycle-support of CIWS are listed. Some of these are conceptual and others are specific.

The root causes for the high cost of maintenance could be outsourcing of the support service and lack of preventive maintenance. Lack of preventive maintenance may be because of lack of resources (such as money and logistic support). High cost of corrective maintenance can be traced to increases in CASREPs and a high percentage of tech assists. High CASREPs are caused by lack of quality or unavailability of parts on board, which may also be due to logistic support. Lack of expertise and training are the foundational cause of tech assists, which can be again traced to outsourcing of maintenance. All the “cans” and “mays” need to be studied further.

On the other hand, in the past, if a ship needed a repair it was accomplished at any cost. Learning from the “high-cost/low-availability” syndrome of this system, it will be beneficial to more specifically research the tradeoff between the escalating repair cost and the availability of that ship and/or system. However, analyzing the effects and costs of *not* performing necessary repairs is a common practice in the private industry. Should the same standards be applied to Defense? Should a new strategy of repair be: repair only if the system fails certain critical criteria, but not at any cost? Should a ship be run like a private enterprise? Should the person in charge of the ship also be accountable for the cost of running the ship? These questions need serious consideration.



The PEO IWS office has projected that data on the results and effects of Class A overhauls will be available in 2005. This data should be analyzed to validate this initiative. Funding for Block 1B is available, but an optimal schedule needs to be set that will achieve the objective of improving  $A_0$  for CIWS using the least amount of monetary resources. Likewise, simply the availability of funds does not guarantee the installation of modifications and upgrading of the fleet. The initiatives to improve MTBF also have to be validated for the “biggest bang for the buck.” The sample points, at this writing, are too few to draw any conclusive trend. But, as the data becomes available, a study conducted to validate the implementation of these overhauls will help document the lessons for CIWS support in the future.

The diversification of CIWS baselines, which occurred over time, contributes to the high cost of maintenance. More baselines simply increased complexity. Several types of mounts need a wider variety of parts and people with different ship-board expertise. Logistics for a line of products that have a large variance is a complex state of affairs. Maintaining the inventory of and expertise for parts with diversity costs more. Some of this expansion is deliberate, whereas in some cases it is forced due to evolving security issues or strategy or both. In the case of CIWS, diversification occurred because of the system’s unique place in the weapon system and rapidly-changing defense needs. But there is a lesson to be learned here: diverse baselines have high variable costs.

On the other hand, if there is only one baseline—a uniformity of parts to be stored and a unified way personnel are trained—then the economies of scale will bring costs down. However, there is benefit in starting small and expanding in scope and scale gradually. The spiraling concept, otherwise known as spiral development, can work economically without compromising operational availability. This process—introducing a prototype or a small number of products and then gradually expanding the original product or enhancement through the fleet—propagates the product line in two dimensions, scale and scope, especially when the end product is not known. Some of this “spiraling” is deliberate, whereas in some cases it is forced due to evolving security



issues or strategy or both. Fixed cost is generally low, but a break-even analysis between uniform baselines and spiral development, addressing both initial and sustainment costs, should both be researched for future, as well as current, systems.

A schedule for performing Class A overhauls for CIWS systems is in place until FY13. Scheduling is done based on various factors such as age of the mounts, status of the mount (Block 1 or Block 1A), availability of the ship, etc. The dynamic of this schedule changes as the requirements of the fleet change. Though at present there is a procedure and a schedule in place, use of optimization techniques will be necessary to find an optimal schedule. Design of the optimal schedule for Class A overhauls will be subject to the constraints of the following conditions, including but not limited to: older mounts converted first, availability of ships, available budget, and uniform mounts.

There are numerous MTBF initiatives in place. Each initiative is associated with its cost and improvement. The optimization model known as “knapsack problem” (or a version of that) will help uncover the optimal plan of action.

The conclusions of this report suggest there is a need for more in-depth studies, research and investigation. Such studies need to be completed for the benefit of the current status of CIWS as well as future sustainment/life-cycle support trade-offs.

**Lessons learned from CIWS can benefit future acquisitions of weapon systems and their maintenance.**

## 4.2 Funding Initiatives

As the mounts in the Phalanx weapon system are converted, they need to be maintained. The fact is that for maintainability, logistic support is an economic and essential part of the system. Therefore, it is critical that operation and maintenance (OMN) receive the necessary funding.

Additionally, though CIWS has been funded for Class A overhauls, there is no funding available for research and development. Yet, history suggests that as the needs for defense changed, the strategies changed; therefore, CIWS went through various





transformations from Block 0 to Block 1B. Therefore, exploration of potential future trends and investigation of possible changes CIWS may need to undergo is critical. An R & D line would have been beneficial for the life-cycle support of CIWS. However, at present or in the future, if CIWS is to be replaced by the Rolling Airframe Missile, then the allocation of past—but not future—R & D funding can be rationalized.

In summary, the research studies, analysis of lessons learned, and forecast of funding will help in optimizing the life-cycle support for the Phalanx weapon system.



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