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A Diagnostic Approach to Weapon System Lifecycle Support: The Phalanx Close-in Weapon System

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Abstract

This study discusses a diagnostic approach to examining the lifecycle support system of a weapon system—specifically illustrating the approaches for the US Navy Phalanx Close-in Weapon System (CIWS). The study gauges the status of current readiness and analyzes a snapshot of cost structures. The study identifies the program's influential cost factors and system performance drivers. As a diagnostic approach to the lifecycle support of the Phalanx Weapon System, the study creates a hypergraph describing the relation between factors and drivers and their effect on operational readiness. The research also suggests areas for further study.

Keywords: Phalanx, Close-in Weapon System, optimization, operational availability, reliability metric, casualty reports, lifecycle support, logistics

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Introduction

Program Managers are charged with managing the cost, schedule, and performance of their assigned programs. As Department of Defense (DoD) weapon systems become increasingly complex with advanced technologies, the program manager is challenged with mastering the various tools for monitoring and controlling the weapon system's cost and performance. In addition, with the current trend of extending the lifecycle of the DoD's weapon systems, the program manager's job of managing the costs during the sustainment phase of the weapon system's lifecycle is becoming even more critical and challenging. The purpose of this article is to describe the use of a diagnostic approach for analyzing weapon system lifecycle support. We illustrate the analysis using the US Navy's Phalanx Close-in Weapons System (CIWS) as an example. First, we offer a history of the Phalanx CIWS as both background and motivation for our research. We then describe a snapshot of total ownership cost estimates during the 1998-2002 period. We use these cost estimates to investigate influential cost factors. Next, we discuss the weapon system performance drivers. Our contribution to the diagnostic discussion is the connection we make between performance drivers and influential cost factors. We conclude by summarizing this relationship as it refers to CIWS. Our focus in this article is not specifically on the Phalanx weapon system itself, but more on the use of a diagnostic approach for analyzing weapon system lifecycle support. The contribution of this research is on the application of this diagnostic approach to any defense weapon system that exhibits the same total ownership cost characteristics as the Phalanx.

History of the Phalanx Close-in Weapon System

The Phalanx Close-in Weapon System (CIWS) was developed and built by Raytheon Corporation to be a fast-reaction, rapid-fire, computer-controlled system with radar and Gatling gun designed to engage Anti-ship Missiles (ASM). The CIWS is also designed to defend against small, high-speed surface craft, helicopters, and general purpose aircraft in open waters, coastal waters or in port (Dutton, 2003). Phalanx is capable of searching, detecting, evaluating, acquiring, tracking, and firing against anti-ship missiles, and provides 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.

CIWS has evolved substantially since its first inception. 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 (*Phalanx RM&A Handbook*, 2004). In the past few years, the Phalanx overhaul program 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) performed a thorough ("Class A") overhaul, which 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 requirements evolved to meet emerging threats.

The total ownership cost statements (LeClaire, 2003), the expenditure of funds (Chaparro, 2003), and the funding history (CIWS Funding History, n.d.) of the CIWS system all suggest the costs for overhauls escalated, while sponsor funding became erratic. The funding issues and the soaring costs forced the Class A overhauls to be replaced by much less comprehensive Class B overhauls. Class B overhauls are also more dependent on the observed condition of the mounts. The Class B overhaul effort that started in 1999 and was in fleet use for three subsequent years did not meet expectations in service reliability (Dutton, 2003) or cost. From 1998 to 2002, overall ownership cost increased 53%. From 2002 to the projected cost in 2003, costs increased 28% (Chaparro, 2003). However, funding during these years did not consistently follow the same increasing pattern: $47.26 million in 1999, $21.76 million in 2000, $46.17 million in 2001.

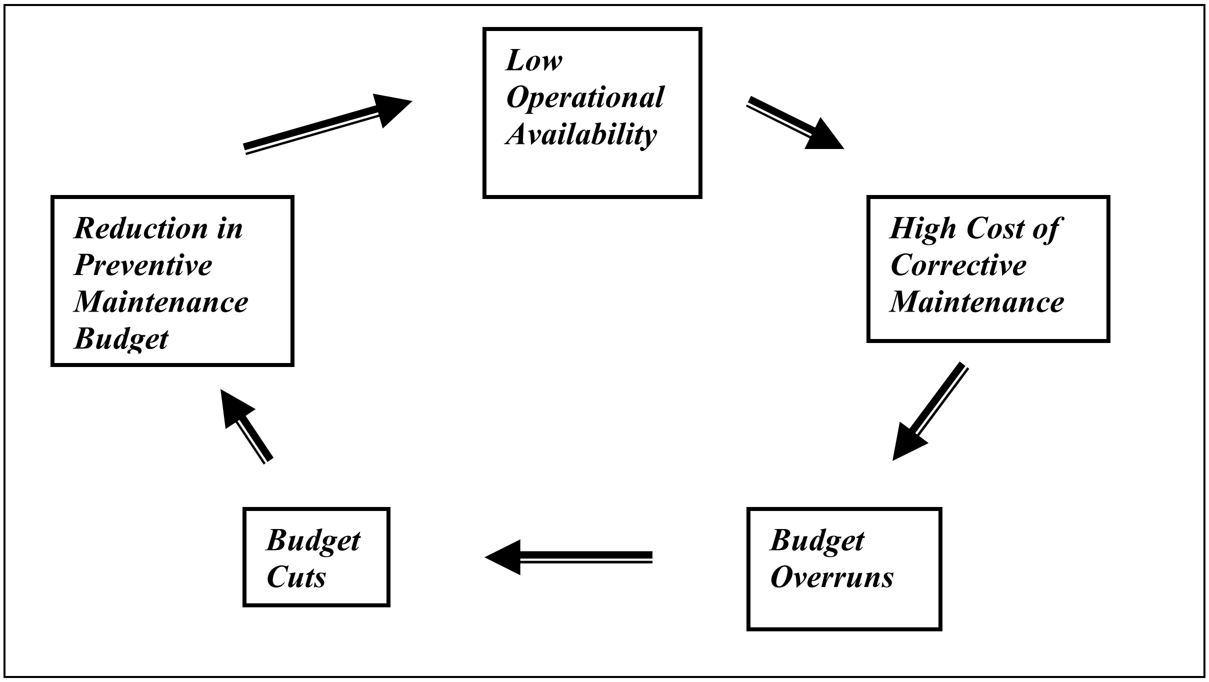
Diagnostic Discussion of the Phalanx Weapon System

As previously stated, the CIWS is a complex, mature, large, and diverse weapon system. At one point it, was observed that CIWS was deployed on 158 ships, using a total of 308 mounts with six different baselines. The different baselines for these mounts lead to increased logistical complexity in terms of provision of necessary spares—which places a heavy burden on inventory managers and, in turn, strains the maintenance staff on the ship. However, this interdependent complexity suggests that solving one problem will help cure many of the difficulties caused by the root problem. Thus, probing deeper to isolate such a problem is worth the time and resources. When we analyzed this interdependency, we settled on the categorization of specific problem areas, which we divided into areas that need further in-depth investigation, areas for further analysis based on available data, and areas in which certain initiatives (at least for the Phalanx system) are in place. If the operational readiness level of the system is not up to an acceptable standard, the maturity of the system suggests that due to years of operations, data to investigate the root cause is available. Collection of data from the various activities linked to the system may result in better understanding of the structure of the problem. In addition, because the large population of the system magnifies small cost increases, it also suggests that small savings in individual components will result in large overall cost reductions.

At the time this research was conducted, the Phalanx CIWS—based on the literature reviewed, data analyzed, and our communication with PEO (IWS) personnel—seemed to be caught in a vicious circle of high cost but low operational availability.

Focusing on the factors causing high cost, we understand that low operational availability leads to higher maintenance costs. Cost overruns prompt budget cuts, which result in reduced preventive maintenance, further resulting in reduction in operational availability. This downward spiral was observed in the case of the Phalanx weapon system, as will be discussed below. Lack of funds reduces the preventive maintenance budget, which lowers operational availability, which forces high-cost corrective or unscheduled maintenance. Figure 1 illustrates this vicious circle.

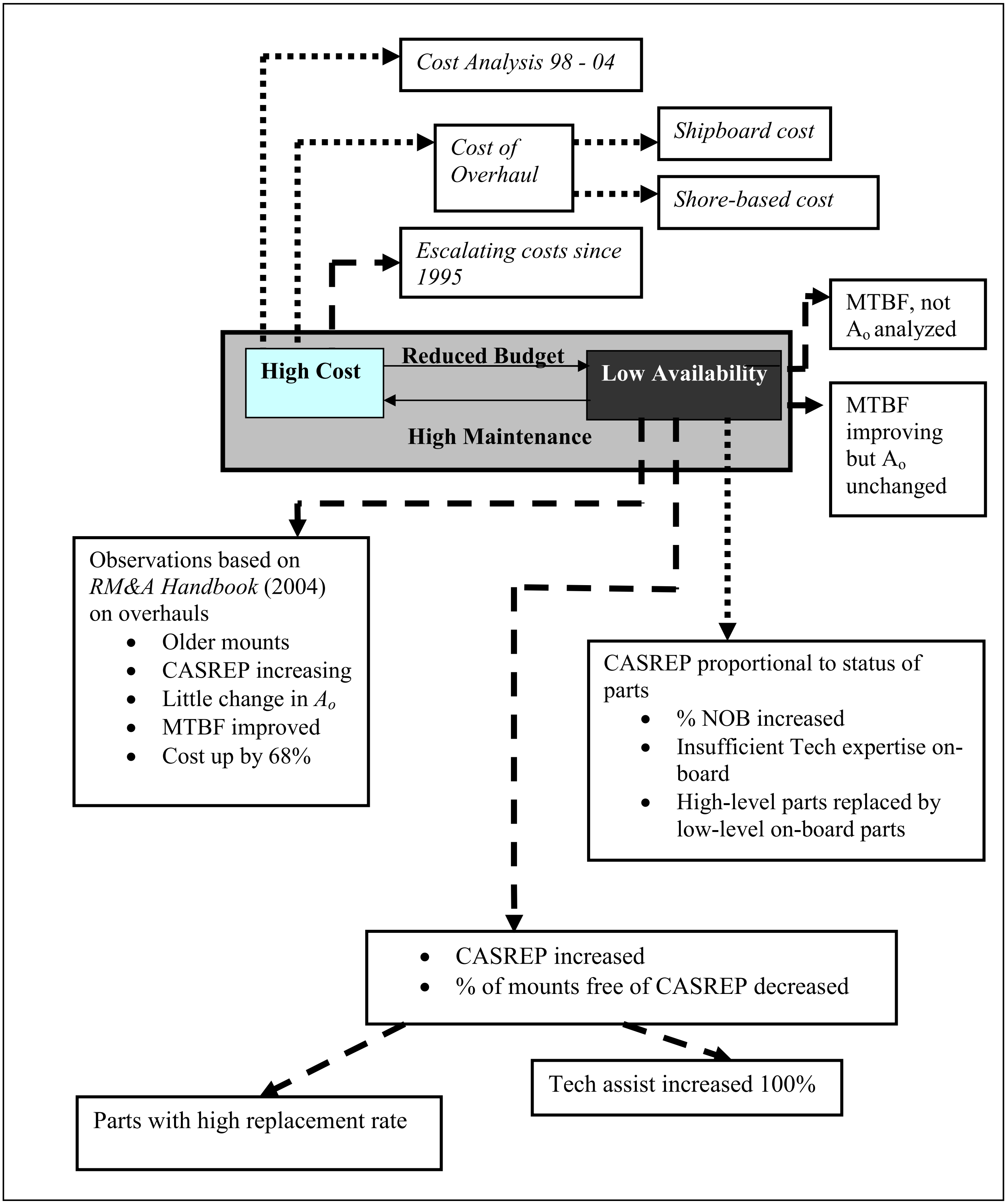
Figure 1. The Vicious Circle



Analysis of Performance Drivers

The influential factors in the "high cost but low operational availability" syndrome are typically costs, reliability, and the underlying factors of both: casualty reports. Our observation of the Phalanx weapon system proved to be similar. In order to gain insight into the snow-ball effect of this syndrome, we analyzed the performance or lack of performance drivers. The major drivers indicated by our research are various costs, casualty reports and parts on-board, reliability metrics used and the type of overhauls. 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, we mapped the issues involving operational availability and cost drivers of the CIWS into a hypergraph of observations. Figure 2 shows the hypergraph mapping the performance drivers. At the center is the "high cost but low operational availability" syndrome. Dashed arrows suggest more in-depth investigations of the current status. Dotted arrows lead to areas that need further analysis based on available data. The following is a discussion of the performance drivers and influential factors for this "high cost but low operational availability" syndrome.

Figure 2. Hypergraph of Interdependencies



Cost Analysis

In order to understand the CIWS' cost issues, we researched the total ownership cost of the Phalanx weapon system for a certain time window. We would like to point out that the cost data was a snapshot taken from the life of the Phalanx weapon system in order to provide insight. This research is not lifecycle cost analysis of the timeline from then to present. Preliminary analysis of Total Ownership Cost (TOC) based on research by Chaparro (2003) and LeClaire (2003) 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 the Original Equipment Manufacturer (OEM) Depot. These costs are analyzed based on our 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). We provide our analysis of this premise later in this study. Our focus is on the functional entities contributing to MSRT and MOADT—which are the ISEA, NAVICP, and the OEM Depot.

Table 1. Observations Based on NAVSEA TOC Data

Department	Change from FY98 to FY02	Change from FY02 to projected FY03
ISEA	+ 7%	+ 40.5%
NAVICP	+ 299%	+ 28.8%
OEM Depot	+ 269.1%	+ 23.1%

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 299% from FY98 to FY02, whereas the projected cost increase for FY03 rose only 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 increases are summarized in Table 2.

Table 2. Observation Based on TOC Data from (Chapparo, 2003)

Department	Change from FY98 to FY02	Change from FY02 to projected FY03
ISEA	+ 12%	+ 42.6%
NAVICP	+ 39.9%	+ 23.8%
OEM Depot	+ 286%	+ 23.6%

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 3. Comparison between TOC of NAVSEA and Cela (1994) Data

Department	Change from FY98 to FY02		Change from FY02 to projected FY03	
	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 were 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.

Cost of Overhauls

As weapon systems get older, they have to be overhauled if they are to continue to function. Certain parts pose more than average problems due to their limited life. Phalanx mounts include such "limited-life" parts. As the mounts are maintained, component 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 may happen that this part is at the end of its lifecycle. Then, when a "newly" overhauled mount is used, the individual part may fail, thus reducing 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. These overhauled mounts are installed on ships based on their availability. However, it needs to be pointed out that mounts removed from one ship are not necessarily reinstalled on the same ship.

Casualty Reports and Parts On-board

A casualty report is initiated when the system needs corrective maintenance and parts or expertise is not available for the required maintenance. There is a clear relation between casualty reports (CASREPs) and the availability of parts needed (*Phalanx RM&A Handbook, 2004*). One of the critical facts is that the parts that cause CASREPs are mostly the problem parts which are replaced in Class A overhauls. Some of the factors contributing to this phenomenon are: increase in the percentage of not-on-board (NOB) parts, and replacement of high-level parts by on-board low-level parts (*Phalanx RM&A Handbook, 2004*), as in case of Phalanx. On a ship, defective parts have to be replaced by parts available: on-board repair parts (OBRP). This leads to more and frequent CASREPs, generating an almost continuous broken-replace-broken cycle. CASREPs increase, and, the days to casualty-corrected reports (CASCOR) decrease—but this seemingly quick reaction time to correct the malfunction does not necessarily improve the reliability of the system. The reason may be due to the fact that the same problem parts cause the same malfunctions.

Escalating Costs

For Phalanx CIWS, after almost twenty years since its initial installation, costs of Class A overhauls started to escalate starting in 1995 (Dutton, 2003; 1995). After the initial installation, the CIWS began upgrading as the needs of the Navy changed. The Block 1 upgrades were completed at Naval Ordnance Station Louisville (NOSL). In 1995, under the Defense Base Realignment and Closure (BRAC) process, NOSL was slated to close. However, the facility was purchased by the Commonwealth of Kentucky and leased to the prime contractor, who continued the overhaul program. The costs for overhauls may have escalated due to the depot transition. But higher costs often lead to a reduction in the number of repairs that can be funded, degrading the overall quality of available assets. The increased cost for Class A overhauls resulted in a decision to downgrade to Class B overhauls (Dutton, 2003).

The Reliability Metric

The reliability literature (Blanchard, 2003) and the *Military Handbook for Operational Reliability* (Office of the Chief of Naval Operations, 2003) define A_o, operational availability, as the quotient of “up time” over “total time.” This equation is the performance measurement of a system.

$$A_o = \frac{MTBF}{MTBF + MTTR + MLDT} \tag{1}$$

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. Therefore, MLDT includes mean supply response time (MSRT), mean administrative delay time (MADT), and mean outside assistance delay time (MOADT).

Available documentation related to the Phalanx CIWS suggests that MTBF (system reliability) has been reviewed, and that the comparison of MTBF across the weapon systems and MTBF versus the age of the system is well documented. As upgrades for CIWS have been introduced, MTBF has increased (Dutton, 2003; *Phalanx RM&A Handbook*, 2004). As demonstrated in Table 4, the Phalanx MTBF has significantly increased. However, MLDT also has increased.

During this time period, a fairly constant A_o trend (*Phalanx RM&A Handbook*, 2004) was observed. A_0, MTBF, and MLDT for anti-air warfare (AAW) and anti-surface warfare (ASuW) compared over FY01–FY03 are given in Table 4. 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 was no benchmark available for A_o at the time of this writing. The decrease in A_o over 10 years, though explainable, is intriguing for its impact on readiness.

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

	AAW				ASuW		
	01	02	03		01	02	03
A_o	0.75	0.65	0.81		0.74	0.69	0.72
MTBF	561	649	795		693	622	549
MLDT	136	220	142		122	150	174

Casualty Reports

As discussed earlier, changes in the frequency of CASREPs are proportional to the status of the parts, working and spare, and inventory levels. During this specific time window, 1999 – 2003, the number of CASREPs increased by at least 5% (*Phalanx RM&A Handbook*, 2004). In 2003, it was observed that the percentage of mounts that were CASREP-free dropped from 95% to 90%. So, not only were there more CASREPs, but they were distributed across the fleet.

Based on the data available, technical assistance requests had increased (*Phalanx RM&A Handbook*, 2004). In fact, the tech 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%. 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 continue to increase greatly.

The Overhauls

The relation between CASREPs and the age of the mounts, though intuitive, is validated by data from Phalanx. Specifically, 71% CIWS mounts were 6 years or older. After an overhaul, CASREPs increase with time. Required overhauls increase as mounts get older. Hence, as more time passes since overhaul, the more CASREPs occur. As more years pass after overhaul, costs escalate further.

Analysis of Influential Factors

We now probe into the factors influencing the “high cost but low operational availability” syndrome by investigating costs, reliability, and issues forcing casualty reports. To do this, we will utilize the hypergraph we constructed for a generic weapon system having the characteristics of Phalanx CIWS. We base this on the status of these factors at the time of research and interviews with subject-matter experts involved in strategic recommendations and the actual operations of the Phalanx weapon system.

Reliability or Operational Availability?

The reliability literature (Blanchard, 2003; Office of the Chief of Naval Operations, 2003) suggests that improving MTBF alone does not necessarily improve A_0. A_0 also depends on MTTR and MLDT; hence, these parameters need to be analyzed. Recall equation (1),

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

A_0 depends on all the three parameters, but we now prove that their influence on A_0 is not the same. For simplicity, we follow the following notation:

$$w = A_0$$
$$x = MTBF$$
$$y = MTTR$$
$$z = MLDT$$

Clearly, $x, y, z > 0$

$$w = \frac{x}{x+y+z} \Rightarrow w > 0$$

We now make the following plausible assumptions,

Assumption 1: Given that normally A_0 >50%, $x > y + z$.

$$(w > \frac{1}{2} \Rightarrow \frac{x}{x+y+z} > \frac{1}{2} \Rightarrow 2x > x + y + z \Rightarrow x > y + z)$$

Assumption 2: Parameter y (MTTR) is normally a small number, whereas parameter z (MLDT)—which includes mean supply response time (MSRT), mean administrative delay time (MADT), and mean outside assistance delay time (MOADT)—is a larger number. Therefore, $z > y$.

Based on these assumptions, we now prove the following propositions,

Proposition 1: Absolute value of the first partial derivative of A_0 with respect to (w.r.t.) x (MTBF) is less than the absolute value of the first partial derivatives w.r.t. y (MTTR) and z (MLDT).

Proof:

$$\frac{\partial w}{\partial x} = \frac{1}{x+y+z} - \frac{x}{(x+y+z)^2} = \frac{y+z}{(x+y+z)^2} > 0$$

$$\frac{\partial w}{\partial y} = -\frac{x}{(x+y+z)^2} < 0$$

$$\frac{\partial w}{\partial z} = -\frac{x}{(x+y+z)^2} < 0$$

By *Assumption 1*, $x > y + z \Rightarrow \frac{x}{(x+y+z)^2} > \frac{y+z}{(x+y+z)^2}$

$$\Rightarrow \left|\frac{\partial w}{\partial x}\right| < \left|\frac{\partial w}{\partial y}\right| \text{ and } \left|\frac{\partial w}{\partial x}\right| < \left|\frac{\partial w}{\partial z}\right|$$

Proposition 2: Elasticity of A_0 w.r.t. y (MTTR) is less than elasticity of A_0 w.r.t. z (MLDT).

Proof: Let $\varepsilon(w|x)$ be the elasticity of $w(A_0)$ w.r.t. x (MTBF).

$$\varepsilon(w|x) = \left|\left(\frac{\partial w}{\partial x}\right)\left(\frac{x}{w}\right)\right|$$

$$= \left|\left(\frac{y+z}{(x+y+z)^2}\right)\left(\frac{x(x+y+z)}{x}\right)\right|$$

$$= \frac{y+z}{x+y+z}$$

$$\varepsilon(w|y) = \left|\left(\frac{\partial w}{\partial y}\right)\left(\frac{y}{w}\right)\right|$$

$$= \left|\left(-\frac{x}{(x+y+z)^2}\right)\left(\frac{y(x+y+z)}{x}\right)\right|$$

$$= \frac{y}{x+y+z}$$

$$\varepsilon(w \mid z) = \left| \left(\frac{\partial w}{\partial z}\right)\left(\frac{z}{w}\right) \right|$$

$$= \left| \left(-\frac{x}{(x+y+z)^2}\right)\left(\frac{z(x+y+z)}{x}\right) \right|$$

$$= \frac{z}{x+y+z}$$

By *Assumption 2*, $y < z$

$$\Rightarrow \frac{y}{x+y+z} < \frac{z}{x+y+z}$$

$$\Rightarrow \varepsilon(w \mid y) < \varepsilon(w \mid z)$$

In conclusion, first partial derivative of A_0 w.r.t. MTBF is smaller than the first partial derivative of A_0 w.r.t. MTTR or MLDT under *Assumptions 1* and *2*. Since first partial derivatives of A_0 w.r.t. MTBF, MTTR, and MLDT are rates of change of A_0 w.r.t. these measures, *Proposition 1* lets us conclude that change in MTTR and MLDT influence more change in A_0—as opposed to the influence of change in A_0 w.r.t. MTBF. This suggests that change in MTTR and MLDT will affect A_0 substantially more than a change in MTBF will affect A_0.

Secondly, under *Assumptions 1* and *2*, *Proposition 2* implies that elasticity of A_0 w.r.t. MTTR is less than elasticity of A_0 w.r.t. MLDT. This leads to the conclusion that between MTTR and MLDT, MLDT exerts more influence on the elasticity of A_0 than MTTR.

Both of these arguments together suggest that studying MLDT, when A_0 is not acceptable, is extremely important. But more importantly, since the influence MTTR and MLDT on A_0 is considerably more than that of MTBF, analyzing MTBF alone does not necessarily reveal the origin of possible decline in A_0. Therefore, we believe that one must also analyze MTTR—and even more importantly MLDT, not just MTBF.

Therefore, the choice of the reliability metric used should 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 needs to be one of the Key Performance Parameters (KPP) (Boudreau & Naegle, 2003). Without those performance measures in place, improving A_o is futile.

As defined earlier, MLDT includes MSRT, MADT, and MOADT. Analysis so far suggests that MSRT—due to transportation from within and off the ship, especially with high percentage of NOBs—has large value. So does MOADT, due to lack of expertise on-board. To improve A_o, MLDT—and, consequently, MSRT and MOADT—should be improved. We believe that researching MSRT of the weapon system will uncover issues leading to lack of NOB, increase in number of CASREPs, and CASCOR.

If the costs associated with MSRT and MOADT are increasing, it is crucial that their influence on A_o be researched further. The costs of ISEA, acquisition, engineering support, CIWS I & C (Installation & Checkout) spares, ordnance alteration (ORDALT), acquisition support, the Fleet Modernization Program (FMP), support, NAVICP support, performance-based logistics (PBL), the Defense Logistics Agency (DLA), procurement, storage and distribution of consumable spare parts, and the role of the OEM depot 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.

Issues Driving Casualty Reports

It is evident that there exists a relation between CASREPs and certain parts in the mounts. It is a well observed fact in production management that frequently, most of the problems are caused by a fairly small proportion of parts. In the case of Phalanx, Class A overhauls replace this small proportion of the parts all the time. In order to cut costs, replacing these with any available parts already on-board (which will be in varying states) will tend to increase the CASREPs. This occurrence should be investigated further. Likewise, the relation between CASREPs and Class A overhauls should be determined as well.

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 technical assists. The quality of the spares, availability of the appropriate spares, and the frequency of the maintenance—all these things may be the possible causes. Pareto Analysis can assist in finding the top CASREPs requisitions as documented in the *Phalanx RM&A Handbook* of 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 (Blanchard, 2003). Diagnosis should include all these factors, along with the high replacement rate of the parts. The “five whys” procedure of the cause-and-effect analysis will also help reveal the root cause.

CASREPs occur not only because mounts are older, but also because there are no personnel trained for the technology associated 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 critical in reducing the number of CASREPs. Lack of expertise on ships suggests that personnel aboard 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.

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 the funding. This budgeting issue may result in a disproportionate burden the system has to bear due to unanticipated corrective maintenance. This especially was true during the first two years of Class B overhauls for Phalanx; thus, rightfully, the initiative for training improvement had been in place. Technician enhancement training (TET) and gun technician enhancement training (GTET) was being conducted by Fleet Training and Support Center Atlantic (FTSCLANT).

Final Analysis

The research shows that the high cost of maintenance of CIWS and an increase in CASREPs and technical assistance lead to low operational availability. In addition, our hypothesis that change in MTBF alone does not influence change in A_o leads to the derivation that one must analyze MTTR as well as MLDT. In fact, under our assumptions (that typically MTBF is greater than MTTR and MLDT combined, and also that normally, MTTR is a smaller number than MLDT), we observe and prove that the influence MTTR and MLDT on A_0 is considerably more than that of MTBF. Therefore, studying MLDT, when A_0 is not acceptable, is extremely important. But more importantly, since analyzing MTBF alone does not necessarily reveal the origin of possible decline in A_0, we must also analyze MTTR and (even more importantly) MLDT, not just MTBF. In the case of Phalanx, based on Table 4, total change in MTBF was 42%, whereas total change in A_o was only 8% for AAW from 2001 to 2003; this change supports our hypothesis. However, in case of Anti-surface Warfare (ASuW), the numbers were inconclusive. In particular, the diagnostic analysis of the Phalanx CIWS suggests there is a need for further research and investigation in areas of operational availability and reliability. Lessons learned from CIWS will also benefit future acquisitions of weapon systems and their maintenance.

As the mounts in the Phalanx weapon system are converted, they need to be maintained. Logistic support is an economic and essential part of the system. Therefore, it is critical that the operation and maintenance (O&M) program receives particular management attention and adequate funding. Phalanx went through various transformations in response to changing strategies, from Block 0 to Block 1B. Hence, it is critical that future trends for associated changes in the system are explored. The proliferation of CIWS baselines continues to increase the cost of maintenance.

More baselines simply increase logistics complexity. Several types of mounts need a wider variety of parts and people with different expertise on-board. The management of logistics for a line of products that has a large variance is a complex task. Additionally, it costs more to maintain the inventory of and expertise for a diversity of parts with low commonality between installed systems than it does for a uniform system. Of course, proliferation may occur with the normal evolution of operational requirements. In the case of CIWS, diversification occurred because of the system's unique role and rapidly changing defense needs. But there is a lesson to be learned: diverse baselines end in high costs

Conclusion

The current economic environment will continue to tighten the DoD's investment budget. As defense budgets become more constrained, weapon systems development programs may be cancelled or reduced, resulting in the extensions of the in-service lives of many DoD weapon systems. With lives extended, weapon system sustainment (operations and support) costs become even more critical and challenging to manage.

This paper discussed how program managers can use a diagnostics approach for analyzing weapon systems' lifecycle support costs and the cost relationships with weapon systems performance, specifically operational availability (A_o). Although the case used to illustrate the diagnostic approach was the Navy Phalanx Close-in Weapon System (CIWS), our research and analysis demonstrates that this diagnostic approach can be used for any complex, mature, large, and diverse weapons systems characterized by multiple platforms and configurations.

Some issues identified in applying this diagnostic approach warrant further research. These issues include the standards for conducting tradeoffs between the escalating repair costs and the availability of that weapon system to undergo the repairs. In general, in the past, if a ship needed repair, it was maintained at any cost. Lessons learned from the "high cost but low operational availability" characteristics of weapon systems extended past their anticipated service lives will be beneficial to further explore the tradeoff between the escalating repair cost and the availability of that ship. However, analysis of the effects and costs of *not* performing necessary repairs is a common practice in the private sector. Should the same standards be applied to the DoD? 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.

Additionally, as weapon system sustainment functions continue to be contracted-out, research should be conducted on incorporating the contracting factor in analyzing weapon systems' lifecycle support costs and the cost relationships associated with weapon systems' operational availability (A_o). These contracting issues include the use of performance-based contracting approaches, the use of cost-reduction incentives, as well as the adequacy both of DoD contracting officer support and of government oversight of outsourced work. The future DoD budget environment will continue to challenge how these issues affect weapon systems' lifecycle support.

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