

NAVAL POSTGRADUATE SCHOOL
Monterey, California



THESIS

**RELIABILITY THE LIFE CYCLE DRIVER:
AN EXAMINATION OF RELIABILITY MANAGEMENT
CULTURE AND PRACTICES**

by

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March 2002

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AN EXAMINATION OF RELIABILITY MANAGEMENT
CULTURE AND PRACTICES**

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ABSTRACT

The importance of reliable and maintainable equipment in the hands of our service members cannot be overstated. Reliability has been identified as the life cycle cost driver for defense weapon systems. Knowing that the reliability of a weapon system directly impacts upon that system's operational capability and life cycle costs makes it of fundamental importance to the warfighter. In recognition of its importance, it is mandatory for all program managers within the Department of Defense (DoD) to ensure their program accounts for the user's reliability objectives. However, reliability failures continue to disappoint operators, maintainers and testers of DoD systems.

This thesis evaluates reliability management within the acquisition process of Naval Aviation programs. Reliability, logistical, and program management personnel directly involved with the issues of reliability management provided empirical insight to help the researcher identify root causes and risk mitigation techniques that are critical to reliability optimization.

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I. INTRODUCTION

A. PURPOSE

The purpose of this thesis is to examine the managerial methods and practices used to optimize reliability of weapon systems in selected Naval Aviation acquisition programs. Based on the aforementioned, a secondary purpose is to examine opportunities for improvement. The objective of this endeavor is to determine how reliability management can best serve the ultimate acquisition goal of equipping warfighters with the tools they required while maximizing available resources. This analysis may lead to recommendations for implementation by acquisition workforce personnel.

Examination of multiple aspects of reliability management will identify program risks and opportunities to mitigate those risks. Ultimately the goal is to identify reliability management issues, which may affect reliability optimization throughout the stages of the acquisition life cycle.

B. BACKGROUND

The 1998 National Research Council study of Statistics, Testing and Defense Acquisition recommended that, "The Department of Defense and the military services should give increased attention to their reliability, availability, and maintainability data collection and analysis procedures because deficiencies continue to be responsible for many of the current field problems and concerns about military readiness." [Ref. 2] In the period

between 1996 and 2000, approximately 80 percent of Army systems tested failed in excess of half of their reliability requirements during operational testing. [Ref. 12]

Reliability is a fundamental component of operational capabilities of weapon system, as well as a primary cost driver of that system's life cycle costs (LCC). Either of these issues is expected to be of the utmost concern to our nation's warfighters. The combination of operational capability and LCC makes the issue of weapon system reliability, a paramount concern for every acquisition professional. The Director, Operational Test and Evaluation has taken renewed efforts to improve the process of reliability testing in hopes of fielding operationally suitable systems to the end user. [Ref. 13]

However, testing is only one tool available to a program. Multiple opportunities are present throughout the acquisition life cycle to address reliability. Beginning with the initial requirements development, through each iteration of the systems engineering process, and ultimately during post-production support reliability must be planned for, monitored, accessed, and improved during the maturation of a weapon system.

C. RESEARCH QUESTIONS

The primary research question is:

What strategies should Program Managers implement to optimize reliability in their weapon system?

The subsidiary research questions are as follows:

1. **What is reliability and what is its significance within acquisition management?**
2. **What policies and regulations governing reliability management are available to Program Managers (PM)?**
3. **What significant factors contribute to weapon system reliability?**
4. **What strategies are currently used to monitor reliability within an acquisition program?**
5. **How can the program office mitigate risk associated with reliability throughout the acquisition life cycle?**

D. SCOPE

This thesis examined reliability management from a program management perspective throughout the acquisition life cycle. Governing policies and regulatory documents have been reviewed from the viewpoint of a PM with respect to applicability as a managerial tool. The focus of the data collected will be from current systems in various stages of development managed at the Naval Air Systems Command (NAVAIR), and limited to managerial processes, tools and techniques. This research is intended to identify both enablers and inhibitors of effective reliability management. The resulting analysis will aide in the development of a set of conclusions and recommendations applicable to acquisition professionals in current and future endeavors.

E. METHODOLOGY

This thesis sought to determine the current environment for reliability management within Naval Air acquisition. This task was accomplished through a thorough examination of literature, reports, and regulatory documents. Additionally, the researcher obtained information through the conduct of personal and telephonic interviews with acquisition professionals. The final method of data collection was an electronic survey of specific acquisition programs managed at NAVAIR. The survey used was a modification of a previously designed reliability performance survey intended to gather data from within a specific Army Program Executive Office in pursuit of similar research objectives. [Ref. 39]

The information collected during the conduct of the reliability performance survey, was obtained through Government and contractor personnel who had first-hand experience with reliability management and/or reliability engineering. Responses to the survey were instrumental in construction of this thesis. Respondents provided a good cross-section of programs in various stages of the acquisition life cycle. The questions posed were intended to emphasize the perspective of program management on the varied tasks involved with reliability management.

F. ORGANIZATION

This thesis contains five chapters.

Chapter I provides an introduction to the subject of reliability and a basis for the study, outlining the scope,

methodology, and structure for conducting the analysis which will be used to address the research questions.

Chapter II will provide a foundation of information on reliability, regulatory documents and opportunities to affect reliability throughout the acquisition life cycle.

Chapter III will present the information obtained from the research conducted about the NAVAIR programs and the results of the reliability performance survey. This data will indicate how the various programs have implemented reliability management processes and practices and will highlight significant examples and experiences.

Chapter IV will provide the analysis of the collected data and identify the techniques and strategies used to manage reliability within the surveyed acquisition programs.

Chapter V will present findings, address the primary and subsidiary research questions, and make conclusions and recommendations.

G. BENEFITS OF STUDY

The intended beneficiaries of this research are the warfighters within our military services, through the acquisition programs that manage reliability within their weapon systems. The compilation of lessons learned and the identification of processes, policies and strategies pertaining to reliability management can assist any program attempting to apply risk management with respect to reliability performance.

The examination of common practices, issues, and concerns of programs wrestling with reliability issues will provide a stepping stone for improvement or root cause determination for future programs allowing them to capitalize on the lessons of their predecessors.

II. RELIABILITY OVERVIEW

Reliability is the single most powerful lever in all logistics-if it doesn't break it doesn't need support (Ref. 21)

A. INTRODUCTION

"Reliability isn't everything, it is the only thing." [Ref. 17] The nature of National Defense and our system of Government, has led to a complex systems acquisition system that produces equally complex and expensive weapon systems. The costs of the weapon systems combined with the Nation's requirement for defense dictate the need for highly reliable tools placed in the hands of trained warfighters. After spending in excess of 40 million in procurement dollars for an aircraft it simply is not feasible to discard the system when it does not work perfectly. Therefore, it is imperative to properly design and manufacture each system to optimize its reliability potential.

This purpose of this chapter is to establish a common ground and set the stage for the discussion to follow about reliability management. This will be accomplished through a presentation of background information intended to provide a fundamental understanding of reliability and its importance within systems acquisition. Definitions of terms relating to reliability are provided to facilitate in understanding and consistency.

Mandatory and discretionary documentation have been identified and discussed. Additionally, the discussion focuses on the importance of reliability management within

systems acquisition and opportunities to optimize reliability will be highlighted

B. DEFINITIONS AND CONCEPTS

Surprisingly, definitions, as well as the terms themselves, seem to vary depending on the user, service component, specific system program, or source documentation. This seems to be unexpected knowing that the discipline of reliability falls in the realm of engineering, which tends to maintain uniform definitions even while measurement methods vary. [Ref. 7] Prior to the 1996 specification and standards reform, MIL-STD-721 "Definition of Terms for Reliability and Maintainability" appropriately stood as a definitive authority. After the cancellation of this standard several 'authoritative' sources are often quoted.

The IEEE Reliability Society has yet to publish a commercial standard. Mil-STD-785B "Reliability Program for Systems and Equipment Development and Production" remains a common reference, and portions of it often are included in the Statement of Work (SOW). Rome Laboratories' *The Reliability Toolkit* is an excellent reference, and is currently considered a commercial standard for practicing reliability engineers. Finally, the Defense Systems Management College (DSMC) refers to the *Reliability, Availability, and Maintainability (RAM) Dictionary*, by Tracy Omdahl the *Webster's* of RAM terms. [Ref. 7]

There are more than 2000 terms defined in documents reviewed so far, many of which have the same meaning but different definitions. (Ref. 40)

It is therefore, important to have a solid understanding of terms and their usage, relative to a particular project. The following common terms and concepts are provided to give the reader an understanding of terminology widely used within the practice of reliability.

Reliability, Availability, and Maintainability (RAM). Requirement imposed on acquisition systems to insure they are operationally ready for use when needed, will successfully perform assigned functions, and can be economically operated and maintained within the scope of logistics concepts and policies. [Ref. 10]

Reliability. The probability an item will perform its intended functions for a specified period under stated conditions. Informally: It does what it is supposed to, for as long as you need it. Commonly quantified in terms of mean time between failure (MTBF).

Mission Reliability. The ability of an item to perform its required functions for the duration of a specified period. Informally: A measure of system's ability to complete its mission.

Logistics Reliability. The probability that no corrective maintenance or unscheduled supply demand will occur following the completion of a specific mission profile. Informally: A measure of system's ability to operate without logistics support.

Logistics Reliability	Mission Reliability
<ul style="list-style-type: none"> • Measure of system's ability to operate without logistics support 	<ul style="list-style-type: none"> • Measure of system's ability to complete mission
<ul style="list-style-type: none"> • Recognize effects of all occurrences that demand support without regard to effect on mission 	<ul style="list-style-type: none"> • Consider only failures that cause mission abort
<ul style="list-style-type: none"> • Degraded by redundancy 	<ul style="list-style-type: none"> • Improved by redundancy
<ul style="list-style-type: none"> • Usually equal to or lower than mission reliability 	<ul style="list-style-type: none"> • Usually higher than logistics reliability

Table 1. Reliability Requirements and Characteristics
[From Ref. 38]

Maintainability. The probability that an item will conform to specified conditions within a given a given period when corrective or preventative action is performed IAW prescribed procedures and resources. Informally: It is quick and easy to fix when it breaks.

Availability. A measure of the degree to which an item is in operable and committable state at the start of a mission when the mission is called for at an unknown (random) time. Informally: It is there and working when you call upon it.

Operational Availability (A_0). The probability that an item, when used under stated conditions in an *actual* operational environment, will operate satisfactorily when called upon. Informally: It is mission ready when I need it at any random time.

Operational availability is a preferred readiness measure for weapon systems, because it reflects the real-

world operating environment. [Ref. 37] Commonly operational availability is considered: $A_0 = (\text{Uptime}) / (\text{Uptime} + \text{Downtime})$. Downtime consists of both scheduled and unscheduled maintenance and any administrative delays (e.g. time spent waiting for parts not in stock). Therefore, A_0 is what system operators' care most about--Performance on demand.

Mean Time Between Failure (MTBF). For a particular interval, the total functional life of a population of an item divided by the total number of failures within the population. MTBF is the basic technical measure of reliability. [Ref. 10]

Life Cycle Cost (LCC). The total cost to the Government of acquisition and ownership of that system over its useful life. It includes the cost of development, acquisition, operations, and support (to include manpower), and where applicable, disposal.

C. POLICY AND REGULATIONS

1. DoD 5000.2-R, Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs

This regulation sets mandatory procedures to be followed by PMs and has specific identified reliability requirements:

The PM shall establish RAM activities early in the acquisition cycle. The PM shall develop RAM system requirements based on the ORD and TOC considerations, and state them in quantifiable, operational terms, measurable during DT&E and OT&E. RAM system requirements shall address all elements of the system, including support and training equipment. They shall be derived from,

and support, the user's system readiness objectives. Reliability requirements shall address mission reliability and logistic reliability. Availability requirements shall address the readiness of the system. Maintainability requirements shall address servicing, preventive, and corrective maintenance.

The PM shall plan and execute RAM design, manufacturing development, and test activities so that the system elements, including software, used to demonstrate system performance before the production decision reflect the mature design. IOT&E shall use production representative systems, actual operational procedures, and personnel with representative skill levels. To reduce testing costs, the PM shall utilize M&S in the demonstration of RAM requirements wherever appropriate.

This policy applies not only to the system, but also to technical manuals, spare parts, tools, and support equipment. [Ref. 14]

2. DoD 5000.1, The Defense Acquisition System

This directive describes management principles applicable to Defense acquisition programs, provides mandatory policies and procedures for the management of acquisition programs, except when statutory requirements override.

Logistics transformation shall be accomplished through... A support environment that maintains long-term competitive pressures; continuous improvement of weapon system reliability, maintainability, and supportability through technology refreshment and other means; and effective integration of weapon system-focused support to provide total mission logistics and optimum support to the user. Acquisition program

managers shall focus on logistics considerations early in the design process to ensure that they deliver reliable systems that can be cost-effectively supported and provide users with the necessary support infrastructure to meet peacetime and wartime readiness requirements. [Ref. 15]

3. Military Standards and Handbooks

In June 1994, the Secretary of Defense, Dr, William Perry, issued a memorandum entitled *Specifications and Standards—A New Way of Doing Business*. This acquisition reform memorandum was aimed at the acquisition management community in an attempt to increase access to commercial state-of-the-art technology and to facilitate adoption of commercial best practices. Specifically, the Secretary made an immediate policy change requiring programs to use performance specifications and non-Government standards. In cases where PMs determine that exact design solutions are required, and no suitable performance or commercial standard exists, they may use military standards only as a last resort and with the specific waiver approved by the Milestone Decision Authority (MDA). [Ref. 34]

Use of specifications and standards became available primarily as guidance to Program Managers. It appears this was a significant shift in procedure. The use of military standards had been a fundamental component of reliability engineering and management.

The following is a list of frequently referenced military standards and handbooks (Mil-Stds/Hdbks) that,

although they have been cancelled, still remain an available reference on reliability:

- MIL-HDBK-781D Reliability Test Methods, Plans, and Environments for Engineering, Development Qualification, and Production
This handbook details techniques that may be used in reliability test programs but is for guidance only. This handbook cannot be cited as a requirement. [Ref. 25]
- MIL-STD-785B Reliability Program for Systems and Equipment Development and Production
This military standard contains reliability tasks, requirements and rationale, which can be tailored to fit specific program needs. [Ref. 26]
- MIL-STD-1629A PROCEDURES FOR PERFORMING A FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS (FMECA)

4. Other Discretionary References

There are multiple discretionary references available to PMs depending on service and program specifics. Listed below are discretionary references that have application across the spectrum of DoD acquisition programs:

a. *Defense System Management College (DSMC) Series of Technical Management Educational Guides.*

A family of guides written from a non-service specific perspective published by DSMC intended for use as instructional aides and as practical references to be used by acquisition professionals. In both cases they are written for acquisition management personnel who are familiar with basic terms and definitions. Used as a desk

reference, these manuals provide assistance to Government and industry personnel in the execution of their management responsibilities. The following guides have application in the management of reliability programs:

1. *Acquisition Logistics Guide* (December 1997).
2. *Systems Engineering Fundamentals* (January 2001).
3. *Defense Manufacturing Management Guide for Program Managers* (April 1989).
4. *Test and Evaluation Management Guide* (November 2001).

b. Rome Laboratory Toolkits

The Rome Research Site, now part of a consolidated Air Force Research Laboratory system, was formerly known as Rome Laboratory. Their Systems Reliability Division developed and published a *toolkit* intended for use by reliability and maintainability engineers. The Reliability Engineer's Toolkit (April 1993) is a widely used technical reference document as "an application oriented guide."

In 1995 the Rome Laboratory released an updated edition "*Reliability Toolkit*" *Commercial Practices*. The latest edition takes a broader view of reliability engineering and management and addresses both commercial and military needs. [Ref. 37]

5. Navy References

- a. ***SECNAVINST 5000.2B, Implementation of Mandatory Procedures for Major and Nonmajor Defense Acquisition Programs and Major and***

Nonmajor Information Technology Acquisition Programs

This document supports the DoD 5000.2-R instruction on reliability management. Specifically RAM is identified as an integral part of systems engineering process, with emphasis placed on mission needs and reducing life cycle costs. Some direction is provided in reference to reliability analysis.

b. NAVAIR INSTRUCTION 4200.36B, Acquisition Plans

This document provides policy and guidance on the construction of Acquisition Plans within NAVAIR. Reliability concerns are to be addressed by logistic considerations with reference to tailoring and quality assurance requirements.

D. IMPORTANCE OF RELIABILITY, AVAILABILITY AND MAINTAINABILITY (RAM)

Reliability, maintainability and availability of a weapon system directly impact upon that system's operational capability and life cycle costs, thereby making it of fundamental importance to the warfighter. Because of its recognized importance, it is mandatory for all program managers within the Department of Defense to plan for and execute measures to ensure their program accounts for the user's RAM objectives. [Ref. 14]

The importance of reliable and maintainable equipment in the hands of military service members cannot be overstated. Ultimately each system matured through the DoD acquisition system, is statutorily required to be tested and evaluated to determine its operational

effectiveness and operational suitability. Operational suitability most directly encompasses reliability and logistical considerations. Informally a suitable weapon system has been defined as

A system that is available for combat when needed, is reliable enough to accomplish its mission, operates satisfactorily with service personnel and other systems, and does not impose an undue logistics burden in peacetime or wartime. [Ref. 2]

Essentially effectiveness equates to "Does it work?" while suitability equates to: "Can we use, maintain, and support it?" Suitability notably impacts the fielded weapon system; particularly in terms of life cycle costs. It is widely known, within the acquisition community, that the costs of operating and supporting (O&S) a weapon system far exceed the actual procurement costs incurred through the design, development and production of new systems. Figure 1 depicts a historical breakdown of life cycle costs for a typical major defense system. [Ref. 37]

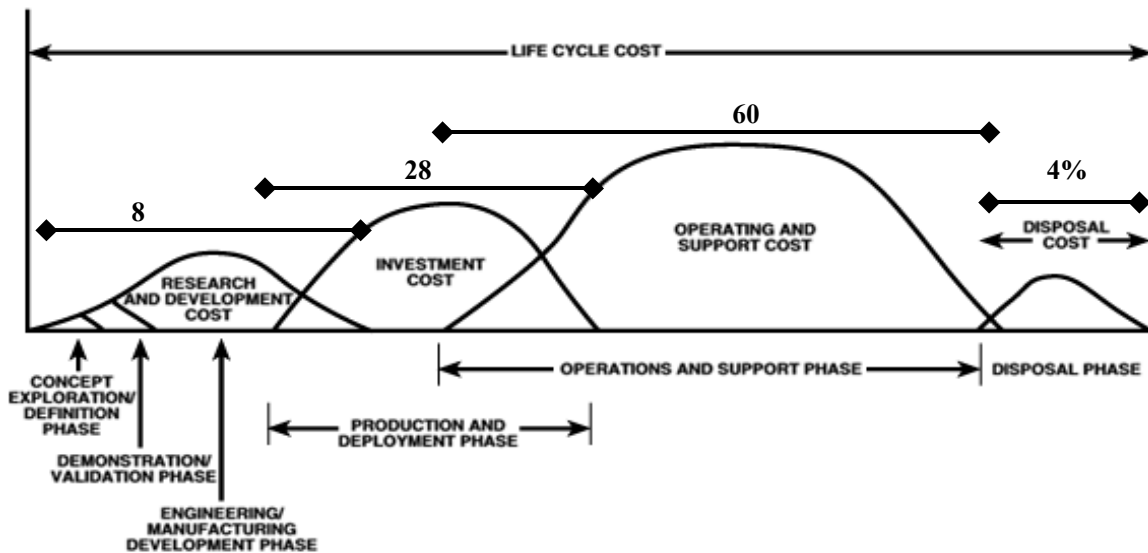


Figure 1. Life Cycle Cost Breakdown of a Typical Weapon System [From Ref. 31]

The life cycle of a weapon system, which began with the initial determination of its need, continues through its design, development, production, deployment and concludes with the system's disposal. As shown in Figure 1, the cost estimation categories are normally separated into four overlapping areas:

- Research and Development. Includes costs of studies; analysis; design; test and evaluation; pre-production article development; and documentation
- Investment. Accounts for all production and deployment costs including any required training and military construction.
- Operations and Support. Consists of all cost associated with usage and maintenance of the fielded equipment.
- Disposal. Although a relatively small percentage of LCC, and therefore often overlooked, this area accounts for demilitarization, destruction, or deactivation of the system. [Ref. 31]

Many factors are involved with the estimation of life cycle costs. Reliability considerations, estimates, and the accuracy of those estimates, play a significant role within each of the four overlapping cost estimation categories. The fundamental objective of LCC reduction analysis is to identify the cost drivers that most significantly contribute to LCC. This allows for trade off considerations with respect to different courses of action.

Although reliability, availability, and maintainability (RAM) are inextricably linked, even often thought of as a single issue, this research will primarily focus reliability. This is because reliability has been determined to be the significant driver of O & S costs. [Ref. 2] Each of these three fundamental logistics

attributes is critical, but both maintainability and availability are directly affected by reliability.

Reliability is the fundamental building block that either supports or hinders maintainability and availability. Maintainability is focused on what happens when an item does break (unscheduled maintenance) and on the level of support required in preventing a system's failure (scheduled maintenance). Simply stated, in most cases the more reliable an item is, the less maintenance attention required. Availability, as discussed previously, benefits from any reduction of time an item spends in a 'non-mission' capable status (e.g. downtime). Optimized reliability, assuming no significant corresponding rise in maintainability, will contribute to the optimization of availability.

Currently the budget of the Defense Department is overwhelming consumed by high costs of O&S. Knowing that 60% to 85% of LCC is consumed in O&S expenditures, there has understandably been considerable effort to identify ways to reduce those costs. The move to increase funds available for recapitalization and modernization of legacy systems, will be paid for substantially through the reduction in O&S costs. Figure 2 depicts a Navy initiative to target methods to reduce O&S costs.

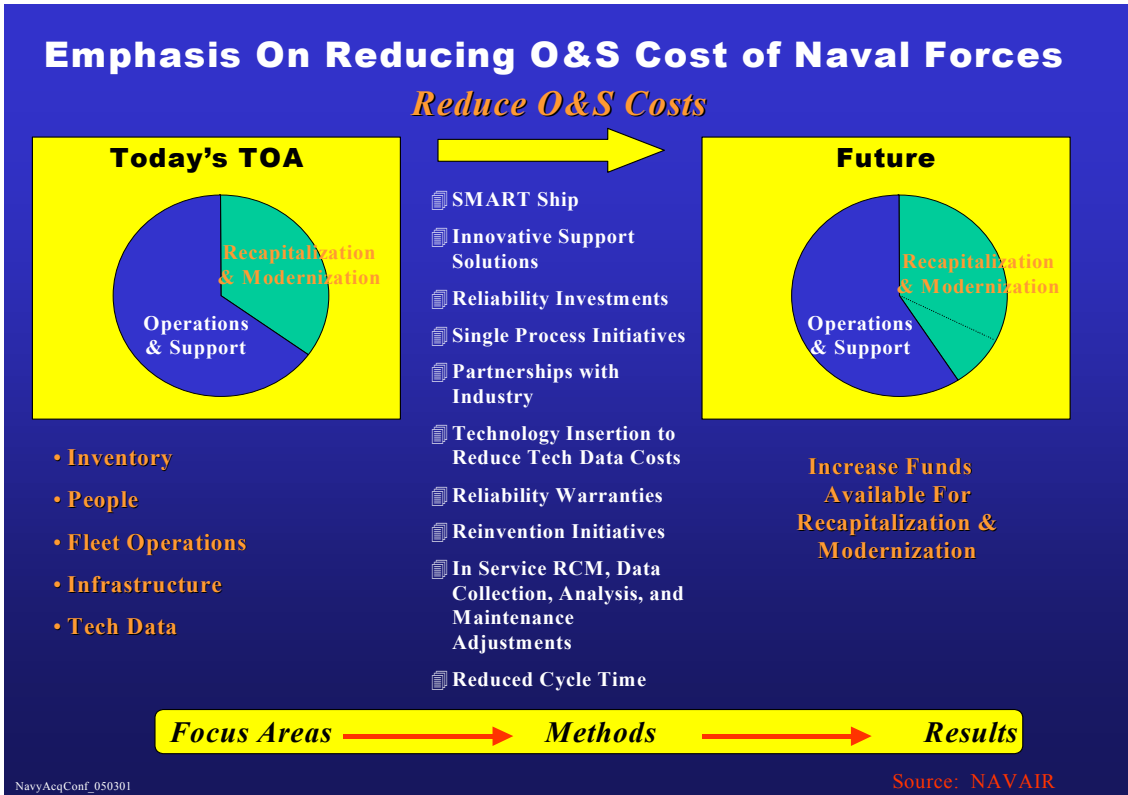


Figure 2. Reducing O&S Costs [From Ref. 35]

Reliability investments and initiatives are clearly on the critical path in the Navy's O&S reduction plan. Reliability has been identified as a cost driver of O&S costs. Figure 3 identifies the cost drivers the Navy intends to address in an effort to reduce O&S by 30 percent. Reliability improvements have been identified as an essential element in the effort to reduce O&S costs on material inventory items. [Ref. 35]

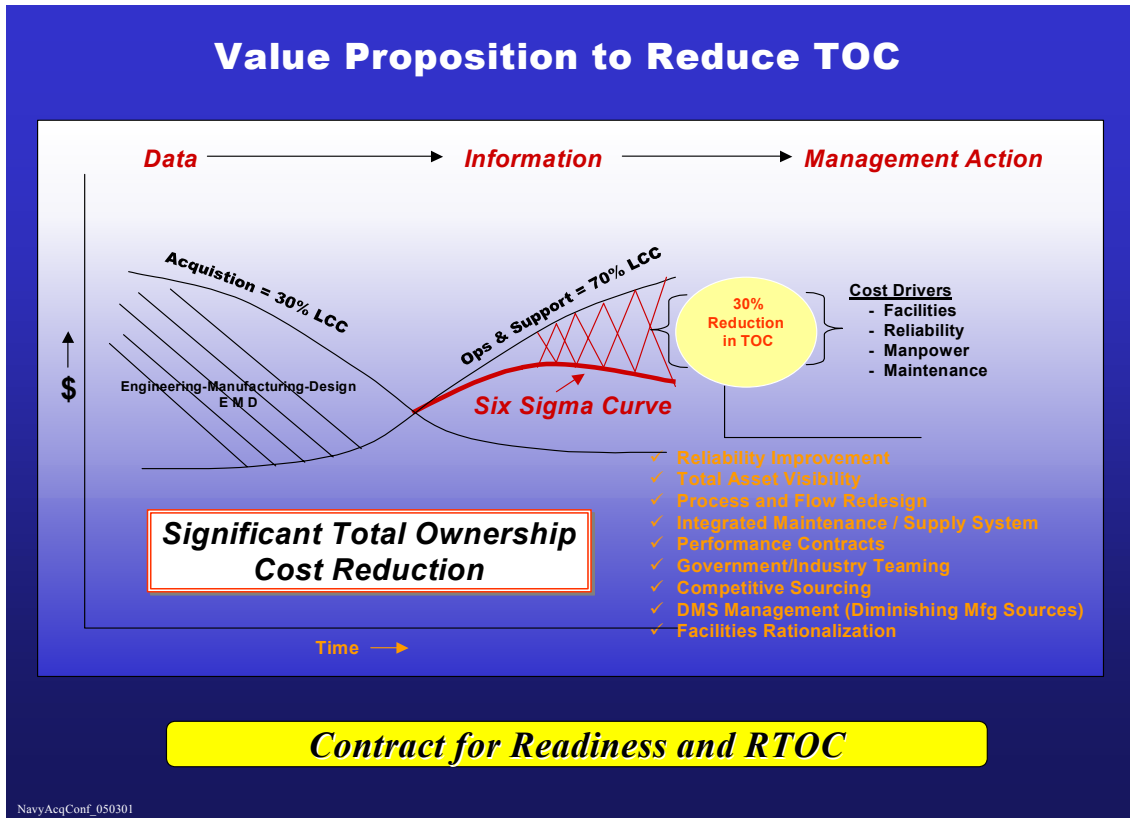


Figure 3. Reliability as a Cost Driver [From Ref. 35]

E. OPPORTUNITIES AND TOOLS FOR RELIABILITY MANAGEMENT

Effective reliability management is achieved through the disciplined system's engineering approach. Systems engineering is an interdisciplinary approach to solve the life cycle technical problems within an Integrated Product Process Development (IPPD) framework. [Ref. 22]

Systems engineering is the management function which controls the total system development effort for the purpose of achieving an optimum balance of all system elements. It is a process which transforms an operational need into a description of systems parameters and integrates those parameters to optimize the overall system effectiveness [Ref. 9]

Combining the structured iterative format of systems engineering with the inter-disciplinary teaming inherent with the IPPD system, provides a program with an opportunity to employ optimum design, manufacturing and support practices. {Ref. 9]

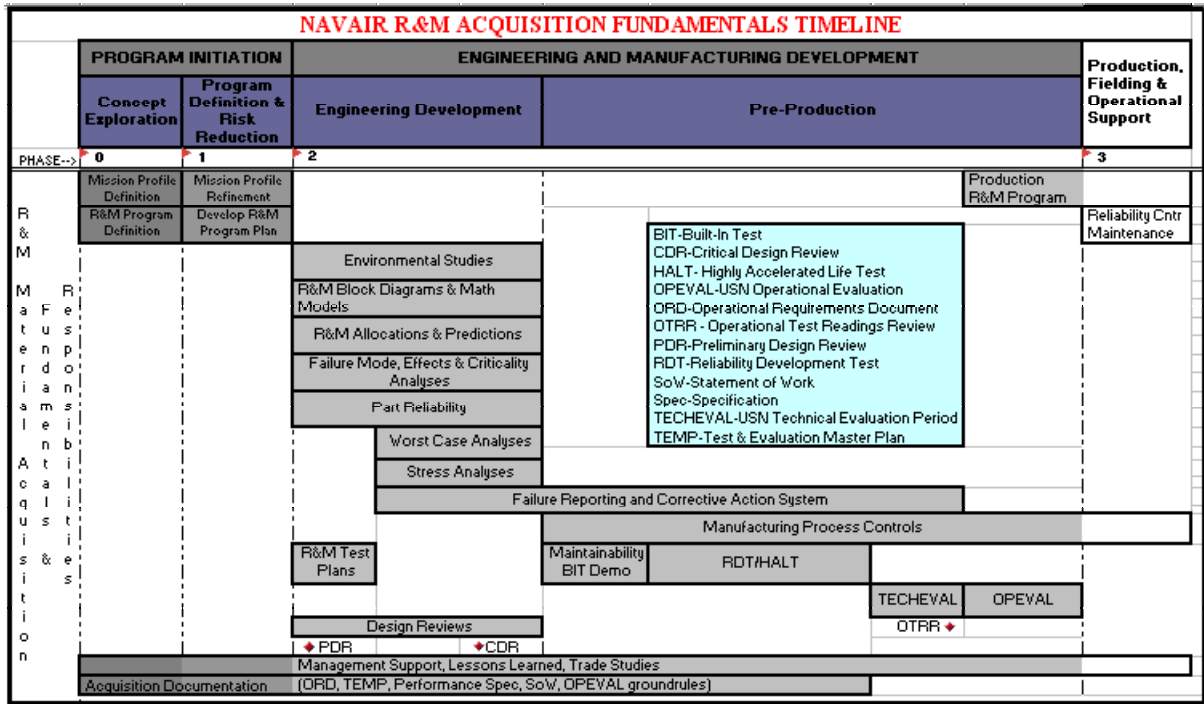


Figure 4. R&M Fundamentals Timeline [From Ref. 30]

Opportunities to influence reliability occur throughout a system's life cycle. Figure 4 depicts some of the reliability fundamental tools, techniques and documents from an acquisition life cycle timeline. Each stage is a building block for the eventual fielding and operation of the equipment by the warfighter. Like SEP itself, reliability management is an iterative task requiring constant attention and optimization of trade-offs.

1. Conceptualization, Design and Development

The first, and most critical, opportunity to successfully manage reliability is at the conception of a need. This is the beginning of the system's life cycle and, an ideal place to have the greatest effect by considering reliability in the original design. Reliability requirements must be grounded in reality, accounting for system usage, expected operating environment, and available technology and resources. The pursuit or acceptance of inadequate, overstated, or simply inaccurate reliability targets can be costly.

The 1994 spec and standard reform not only made a significant change in document usage, it directed all acquisition decision makers to focus on the "problem rooted in the requirements determination phase." [Ref. 34] A fundamental comprehension of the ultimate user's needs is required. A system to be operated in space, aviation, or in a security function demands different reliability requirements than does an administrative computer desktop operating system or a coping machine. Although the ultimate customer wants a reliable system in all circumstances, the consequence of system failures varies. Systems to be operated in space demand high, or ultra, reliability. The cost of a failure, or even the opportunity for corrective action, is prohibitive.

Once mission and environmental profiles have been established, the intended *life* of the system should be determined. This has been a problematic issue for the Department of Defense, but needs to be addressed, as this will affect a new system from the materials required to the

design itself. The design stage also presents the opportunity to consider designing for manufacturing and producibility. Engineers tend to place undue emphasis specific product functions, but SEP should provide a balance that can help maintain perspective during design.

Designing reliability into a system can be achieved through many paths. Techniques such as maintaining simplicity of design, or the selection of particular raw materials all must be balanced with their possible side effects. For example, if a design team chooses to optimize a system's reliability through redundancy of critical components, they must also consider the affect on the logistical burden of increased part storage and maintenance. There are a multitude of tools to assist in the analysis of reliability during design.

Below is a non-inclusive list of reliability analysis tools. Not every tool or technique applies to every program. Each program, it is recommended, should tailor their selections to achieve their desired results.

- Failure Modes, Effects, and Criticality Analysis (FMECA). FMECA is a method to identify potential failure modes, causes and effects, and to rank them by the severity of consequences. This tool can be used to eliminate or minimize potential problem areas or at a minimum provide maintenance tasks to address them.
- Parts and Material Control Program. Parts control enhances standardization and reliability. Controlling the quality of materials/parts used aides in accuracy of reliability predictions
- Reliability Prediction. This technique uses parametric estimations, historical or engineering models to forecast part reliabilities. Prediction estimates are a useful tool but should

only be used when it is followed with verification testing. Although predicted estimates are never identical to fielded results, there are numerous examples of predicted MTBFs that were not even close to the actual performance.

For example, the F/A-18 contains a trailing edge flap actuator that controls a flight control surface. The original equipment manufacturer rated the expected MTBF at 4000 flight hours. The actual performance of this equipment turned out to be less than 400 hours. Whether the cause of the error was from incorrect installation, unintended usage or simply from inaccurate predictions the results were the same. The aircraft availability suffered because of the unplanned maintenance required and the supply system, which was based on the expected failure rate, was unprepared for the increased overwhelming demand.

A hypothesis must be assumed when dealing with predictive reliability: the estimate is incorrect until proven otherwise. The mere acceptance, without proof, of a manufacturer's claim is unwise at best.

- Physics of Failure (POF). POF is a method that uses modeling and simulation to identify mechanisms of failure prior to testing. This technique can help focus future testing and maintenance.
- Highly Accelerated Life Testing (HALT). HALT is performed on a product as part of the design process. A product is stressed beyond its required specifications and beyond what is expected in its intended environment. This is

done to induce failures and identify the actual functional and destruct limits of a product. This differs from tradition verification testing which demonstrates a products compliance with specs. HALT exposes the weakest points in the design in an extremely quick fashion with a minimum of required resources. HALT allows early detection and correction of failure points that previously would not have been discovered prior to fielding. A root cause failure analysis is completed on each failure allowing for implementation of corrective actions. [Ref.16]

- Stress Analysis. A design technique enhanced with computer-aided engineering, intended to identify effects of stress on a system. Through the computer the stress can be conducted in a worst-case analysis. This analysis can help to reduce the region of possible failures and decrease the nominal stress.

The importance of the design phase is demonstrated in Figure 5. Nearly eighty percent of a system's life cycle costs are committed in the initial stages of the design phase. Decisions made on materials and processes to be used, will drive the rest of the program. Mistakes or miscalculations made during the initial design stages will put the program office in a reactive position for years.

Early orientation towards reliability may put a program in a proactive position. Incorporation of built-in-test functions and simple designs with reliable parts, will contribute to the ease of future maintenance requirements. The inclusion of experts from multiple disciplines early in process will identify concerns, which would have been overlooked.

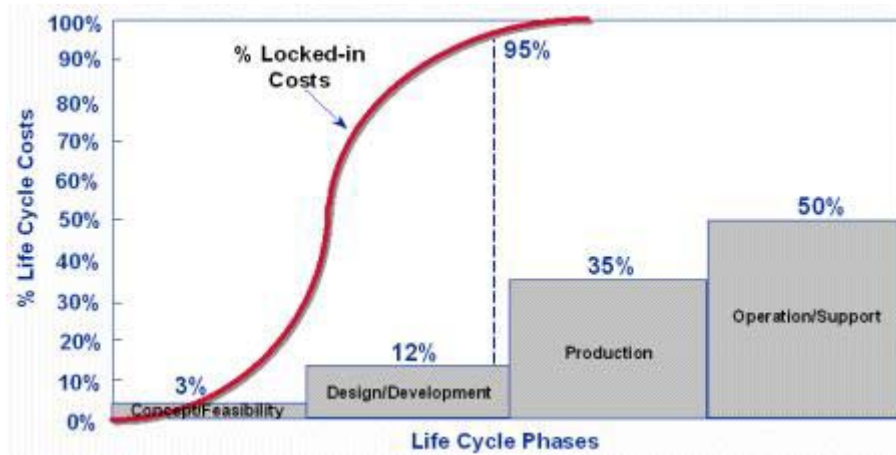


Figure 5. Life Cycle Costs [From Ref. 37]

2. Tests, Production and Verification

A reliability program continues its iterations with each stage of development. The outputs from the previous iteration become the inputs to the present. As systems evolve reliability management must keep pace. Testing and production need to continue emphasizing reliability and stress reduction on the system.

The reliability targets established in the design and development stages must now be tested and verified. The verification of accepted targets is crucial. The logistical support system will be built upon the accepted R&M targets. Production process must also be examined. It is not uncommon for the production to introduce faults into the product. Testing and process controls are the key elements to success at this point.

The production process seems to be often taken for granted. It is incumbent upon the program office to ensure that methods and material used to produce a product do induce reliability problems. Testing and inspection of the

manufacturing process must be completed to reduce opportunities for latent defects or human error.

Test and evaluation (T&E) are invaluable to a successful program. T&E is a part of the acquisition process aimed at getting the best possible product to the warfighter. Some feel that testing is an unnecessary burden that eats into both cost and schedule. T&E does consume cost; both in terms of schedule time and in financial commitment. However, these expenditures serve two primary functions: First, to help develop and make a system work; Second, to determine if a system works and that we are *getting what we asked for*. There are essentially two forms of testing that accomplish these goals: Developmental Test and Evaluation (DT&E) and Operational Test and Evaluation (OT&E). Both forms of testing provide feedback to acquisition decision makers.

a. *Developmental Test and Evaluation*

DT&E is a method for a PM to *make his system work*, to verify contractor claims and predictions, and to influence the system design. DT&E normally aides in product design and development, through a test-analyze-fix-test (TAFT) approach. Both contractors and Governmental personnel can be involved in each of these four stages.

[Ref. 22]

The feedback provided by DT allows the systems engineering process to analyze the test results and devise required fixes or adjustments to be implemented and tested again. Reliability engineers and logistician play a key role through the IPT process. Ultimately design risks are minimized and the system can be certified ready for

operational testing. Listed below are some of the testing techniques and tools used.

- Failure Reporting, Analysis and Corrective Action System (FRACAS). FRACAS is a closed-loop reporting system that plays an integral role in TAFT. The formal reporting of identified issues allows for root cause determinations and corrective actions to be applied. Early initiation of FRACAS provides ample time to address failures prior to full-rate production.
- Environmental Stress Screening (ESS). ESS is an initiative to find potential flaws through the use of thermal cycling and vibrations early in the production process enabling cost savings by identifying problems in the factory while there is time to fix.
- Highly Accelerated Life Testing (HASS). HASS is a screen test performed during the production process. This test is to be completed post HALT and DVT. The goal of HASS is to ensure that no new *weak link* has entered the picture during the production process. [Ref. 16]
- Reliability Development Testing (RDT). RDT or reliability growth testing (RGT) is the centerpiece of TAFT. The reliability growth of the system is emphasized through an iterative design maturation process.

The PM controls the DT environment and is provided with data, throughout this testing cycle, with which he can make informed managerial decisions that can affect the reliability of the final product. Through developmental testers the PM must review contractor reliability programs, monitor reliability tests and review test data and reports. With limited resources the PM must make tough trade-off decisions and ultimately certify that his system is ready for operational test and evaluation (OPEVAL).

b. Operational Test and Evaluation

OT&E is considered the *conscience* of the acquisition process. Unlike DT, operational testing is accomplished by an independent agency not beholden to the Program Manager. Testers are fleet representative users and the testing environment must be realistic of the intended operational environment, including anticipated threat countermeasures. OT&E is designed to stress the system as it will be used by the warfighter.

- Early Operational Assessments (EOA). EOA is conducted prior to Milestone II/B to provide operational / mission input to the decision makers early in the life cycle.
- Operational Assessments (OA). Operational assessments begin post Milestone II/B and signify the start of the OTAs evaluation of system level performance.
- OPEVAL. OPEVAL is a "separate and dedicated phase" of OT&E conducted in support of the full-rate production without contractor involvement. The purpose of OPEVAL is to evaluate a system's Operational Effectiveness and Suitability. Reliability requirements are encompassed within the suitability judgment, and the OTA will conduct enough testing on production representative test articles to make that determination. All supporting publications, logistical support planning and training will also be evaluated.
- Follow-On Test and Evaluation (FOT&E). FOT&E is testing completed after milestone III/C. This testing is generally used to test modifications to production systems or to complete any deferred testing.

The purpose of OT&E can be simplified to the main emphasis: to see if it works. In essence it is a *final exam* for PMs, and the last chance to influence and evaluate

reliability before a system hits the fleet. All reliability targets must have been proven within a confidence level acceptable to the decision authorities.

3. Operations and Support

The program office is responsible to sustain the reliability of their system while it remains in service. It is in this stage of the life cycle where the previously efforts to optimize reliability pay off. PMs are required to "maintain a relationship with the user/warfighter based on system readiness." [Ref. 14]

The collection of field data is essential to proper management. The only true measure of system performance is borne of that systems sustained use in actual conditions. Even with rigorous testing, experience has shown that predicted reliability estimates do not match actual system performance. DoD 5000.2-R charges the PM and the logistic community to measure and support fielded systems, with emphasis on continued improvement.

Corrective actions must be taken to address the differences between predicted and actual performance. If a program elected to *spare to* the predicted reliability levels there may be significant delays and shortcomings within the available maintenance capabilities. Adjustments must be made either within the system itself or within the supply chain.

F. CHAPTER SUMMARY

The reliability of a weapon system directly impacts upon that systems operational capability and life cycle

costs, making it of fundamental importance to the warfighter. It is mandatory for all program managers within the Department of Defense to plan for and execute measures to ensure their program accounts for the user's RAM objectives. [Ref. 14]

This chapter provided a framework of reliability definitions, references, and methods. Additionally, the researcher provided a view of both reliabilities' relative importance in system acquisition and of opportunities within a systems life cycle for a PM to influence the reliability of the system for which he or she is responsible.

Chapter III will present information about the Naval Air Systems Command programs surveyed for this thesis. The results of the survey and interviews will be provided and organized by applicable themes.

III. PROGRAM METHODOLOGY FOR RELIABILITY MANAGEMENT

A. INTRODUCTION

This chapter presents the methodology used and data gathered to address the primary and subsidiary research questions. An overview of the Naval Air Systems Command (NAVAIR) and information on the system programs investigated are provided. Additionally, data from these programs is presented in an aggregate format and summarized based on the responses to the electronic weapon system reliability management survey questionnaire.

Data presented reflects the actions and perceptions of the acquisition workforce dealing with reliability management issues.

B. METHODOLOGY

Research was conducted through a literature search of reliability related documents including Director of Operational Test and Evaluation (DOT&E) Reports, General Accounting Office (GAO) Reports, Department of Defense (DoD) Official Memorandums and Directives, Congressional Subcommittee Reports, Military Standards and Handbooks (Mil Specs), and technical and professional journals, manuals and web sites. Interviews were conducted with current acquisition professionals familiar with program and/or reliability management including personnel from Program Executive Offices (PEO), aviation program management (PMA) offices, contractors, the test community, user representative organizations, and reliability engineering disciplines. Additional interviews were conducted with

personnel from academic disciplines, who have had years of experience in program and reliability management. Interviews were conducted in person, over the phone, or through electronic mail.

All interviews, literature searches and the survey questionnaire were aimed at the primary research question:

What strategies should program managers implement to optimize inherent reliability in their weapon system?

1. Survey Questionnaire

The Weapon System Reliability Survey Questionnaire used was a modified version of a previously designed survey intended to "draw out the practices employed by each PM organization on managing reliability performance risks in their programs." [Ref. 39] Electronic distribution was accomplished with the assistance of the Reliability and Maintainability Competency at NAVAIR. Respondents to the questionnaire included reliability engineers, logisticians, operational and developmental testers, and program management personnel, all of whom had responsibilities associated with reliability within their specific program. A copy of the survey questionnaire is located in Appendix A.

2. Interviews

Interviews were conducted as an additional method of addressing the research question. Follow-up interviews with survey questionnaire respondents were conducted when amplification to their inputs was desired. Additional interviews were conducted to gain insight from individuals who had experience and background in reliability and management issues. The empirical data from interviewees was generally from a supervisory perspective. Generally,

these people consisted of PEO personnel, PMs, competency branch and division heads. Interview formats focused primarily on the thesis research questions, which the interview subjects normally had time to review and respond in writing if desired.

C. PROGRAMS STUDIED

The systems researched were limited to Naval Aviation programs associated with NAVAIR. NAVAIR is a major Naval Systems Command charged with systems acquisition and supporting those systems in the operating fleet. Actual program management is a team effort. Program Managers (PMs) work for a supervisory Program Executive Office (PEO) who in turn reports to the Assistant Secretary of the Navy for Research, Development and Acquisition (ASN (RDA)).

The ASN (RDA) is responsible and accountable for all acquisition functions and programs for the Department of the Navy. The PEOs and PMs are directly responsible for the development and acquisition of Naval systems. As a Systems Command, NAVAIR provides matrix support to PMs including engineering, contracting, and comptroller. Figure 7 depicts the extensive reporting chain for NAVAIR.

Thirteen programs spread throughout the four aviation PEOs and eleven Aviation Program Management (PMA) offices participated in the survey. The represented systems range from pre-program establishment to legacy systems deployed and operated for over 20 years. The programs with designated Acquisition Categories (ACAT) are level I and level II. Perspectives covering additional programs were incorporated through the survey questionnaires and

interviews conducted with personnel in supervisory positions who had responsibility and knowledge of multiple programs.

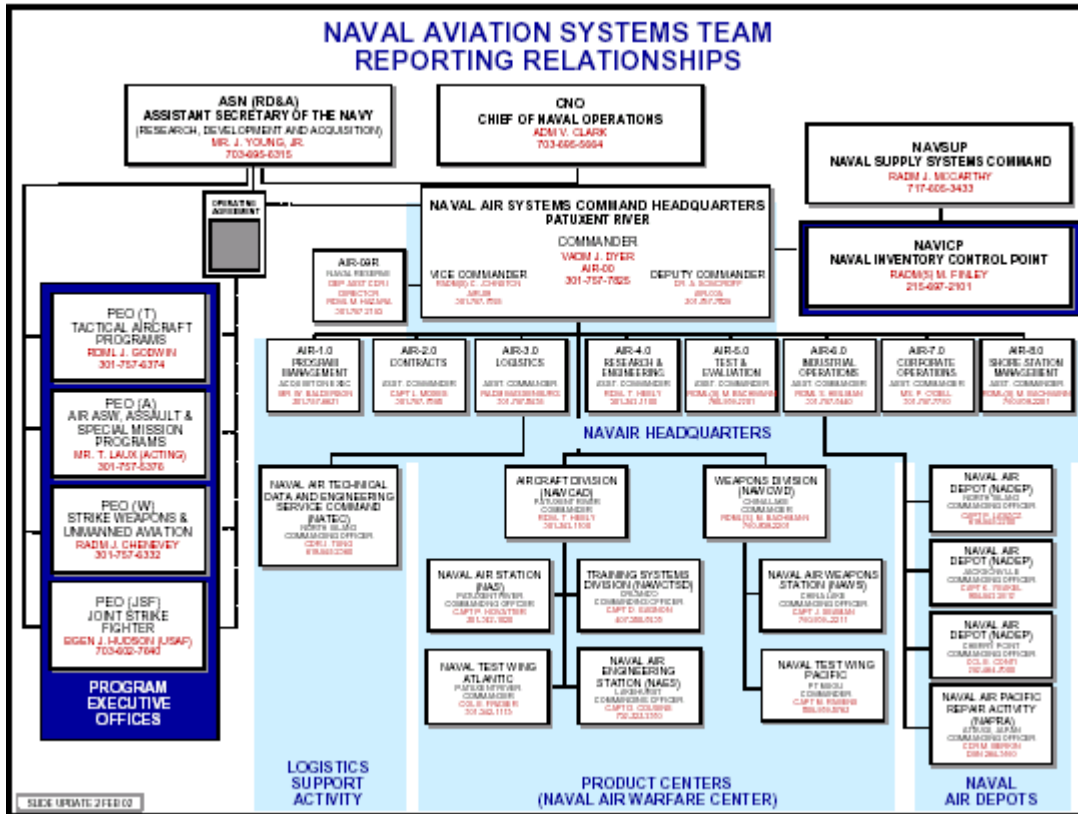


Figure 6. NAVAIR Reporting Chain [From Ref. 30]

D. DATA PRESENTATION

In an effort to obtain disclosure of all issues associated with reliability management, interviewees and survey questionnaire respondents were permitted to provide information under the premise of non-attribution. Though most participants did not seem concerned with attribution, the “political realities of system acquisition” led some individuals to request that they, or their program, not be identified. As such, all program responses will be treated in the aggregate. Participating programs and individual research participants will not be identified, as it would

be too difficult to maintain anonymity for some while identifying others.

Collected data to be analyzed will be organized in the following themed categories:

- Reliability Management Environment.
- Reliability Processes and Tools.
- Reliability of Fielded Systems.
- Affects of Acquisition Reform.

The following sections will present the aggregate data within the same areas of interest. The data summary includes information from all sources of data collection. Where appropriate tables will be used to display questionnaire responses. [Ref. 39]

E. RELIABILITY MANAGEMENT ENVIRONMENT

The first set of data relates to how management approaches the subject of reliability and seeks to identify the cultural environment of reliability management. A series of survey questionnaire questions were intended to draw out the perceptions of respondents on how reliability is managed.

1. Reliability Responsibility

The results tabulated in Table 2 present the questionnaire answers to the following question:

Who within your organization is primarily responsible for reliability activities for this particular program?

This question was fundamental in establishing whether there was a consistent managerial approach. The responses are presented below:

Responsible for Reliability Within PMA	Total	%	Chartered IPT?	
			Y	N
PM	1*			
Project Leader				
Systems Engineering Team Lead	1 (1*)	8%		
Logistics/Supportability Team Lead	4	31%		
Test Team Lead				
Reliability IPT	5	38%	4	1
Prime Contractor	1	8%		
Lead Shared	2	15%		
No One Specifically				

* indicates conflicting response

Table 2. PMA Reliability Responsibility

Response Summary: Responses varied throughout the programs without any unified theme. The largest common response indicated that the Reliability IPT had been delegated primary responsibility for reliability issues. However, less than half of the participating programs even had a formal Reliability IPT. Additionally, two program responses could not identify an individual or team that had overarching authority over reliability activities. Instead they indicated that reliability management did not have a designated *primary authority*, and was purposely a shared responsibility through multiple sources.

One program provided multiple responses to the questionnaire inclusive of the following perspectives: reliability engineer, subsystem IPT lead, and tester. Each individual response identified a different source of "primary responsibility." The PM, Logistics/Supportability Team and Reliability IPT were each identified as having primary responsibility for reliability.

Additional Comments: During an interview, one former PM commented that PMs manage by exception and without a specific problem or issue, reliability and the other engineering disciplines are managed through empowerment of the technical experts. The common theme seemed to be an acknowledgement that PMs rely upon the reliability competency for matrixed support. Reliability experts generally provide input on what reliability activities are suggested and where they should be implemented. How that support is incorporated into a program is dependent on available funding and the PMs judgment based on cost, schedule, technical risk and political environment considerations.

2. Reliability Documentation

Most acquisition activities have an overriding program document that provides structure, priorities, methodology and/or resources for a given topic. For example, the Test and Evaluation Master Plan (TEMP) is the overarching document relating all test activities within a program.

How is the system reliability program and corresponding management approach to such formally documented?

Table 3 provides the survey questionnaire responses.

Reliability Documentation Within PMO	Program Responses	% of Programs
Reliability Program Plan	9	69%
Contract Statement of Work (SOW)	3	23%
Test and Evaluation Master Plan (TEMP)	5	38%
Single Acquisition Management Plan (SAMP)	0	
No Formal Reliability Management Plan	1	8%
Other	1	8%

Table 3. Formal Reliability Documentation

Response Summary: The majority of participating Naval Aviation programs do indeed have an overarching reliability document. Only one program, still in the earliest stages of development, did not yet have any formal reliability management plan. In addition to a Reliability Program Plan, many programs track reliability activities through the TEMP or Statement of Work (SOW).

3. Reliability Resources

Allocation of available resources is inherently a management function. As such, participating PMA representatives were asked to assess the adequacy of reliability resources. Table 4 provides the responses to the following question:

Is the amount of time and funding allotted for reliability testing sufficient for your program?

ADEQUACY OF RELIABILITY RESOURCES		
Current Schedule and Available Funds are Sufficient	Could Use More Time/\$\$ to Reduce Reliability Risk	No Significant Reliability Effort at This Time
4	6	3
31%	46%	23%

Table 4. Adequacy of Reliability Resources

Response Summary: The PMAs that responded that their program had sufficient funding fit into two categories; 1) High visibility programs early in the development stage enjoying positive support and funding or, 2) Legacy programs enjoying considerable support in part due to their current tactical usage.

The PMAs that responded that they currently were not engaged in significant reliability efforts were either early in the defining requirement stage or have just successfully entered fielding after making required adjustments to production articles. The remaining programs fit the more common profile of a program competing for funding and undergoing the scrutiny that is a part of the acquisition process. Knowing that resources are limited, tough decisions often lead to compromise on schedules and priorities effecting system reliability.

Additional Comments: One Reliability IPT member stated that reliability, maintainability and supportability are always the elements that are compromised when executing a program. He further commented that these activities are so essential that they need to be fully funded and not have their schedules so compressed that testing is either severely cut or meaningless.

An interviewed PM said that program management often operates in the *gray area*, and that we knowingly "mortgage the O&M future" to gain production support today. A reliability IPT team leader provided the following discussion on reliability funding:

Reliability costs are largely up front in the design and testing phases and can be rather significant... When we come to testing and fielding and we find shortfalls in the system reliability. Normally the cost to make any reliability improvements comes from the same pot [of money] as system performance improvements, which usually win out over reliability. The programs need to have a contingency fund for reliability and maintainability fixes. Early in the program when there are few units in the field this would have a very good chance of providing a

quick payback in logistics savings.

The general consensus of comments can be summed up with the following quote:

We will either pay for it up-front or the fleet will pay for it in terms of reliability or maintainability once it gets fielded in the fleet.

4. Reliability Regulations and Policies

Regulatory documentation is a reflection of the attention paid to a subject by higher headquarters.

Are you aware of any specific DoD or Navy policy regulation regarding weapon system reliability management?

Table 5 summarizes the responses.

Reliability Policy Awareness?	Program Responses	%
YES	4	31%
NO	4	31%
NOT SURE	5	38%

Table 5. Reliability Policies and Regulations

Response Summary:

Programs that replied yes identified the DoD 5000.2-R, specific program documentation, or the cancelled military specifications and standards. Nine out of 13 programs, and 12 out of 18 questionnaire responses, stated that they were unaware or unsure of any policy or regulation regarding reliability management. Most responses and interviews further commented on frustration with a lack of useful documented guidance.

Additional Paraphrased Comments: The following comments are paraphrased responses:

- DoD 5000.2 and not much more; with acquisition reform the Government backed off military specs and standards.
- There has been a reduction in the design fundamentals [MIL-STD/HNDBK] throughout the 90's.
- Some PMAs were told to shift to commercial best practices, unfortunately the contractor does not always know better.
- Reliability engineers continue to use the cancelled military specs and handbooks because there has been nothing to replace them.
- Some reliability engineers just *cut* portions of MIL-STD-785/781 and paste them into the Statement of Work (SOW).
- At program initiation the Willoughby reliability improvement initiatives were included in the specification.
- "If you identify some, please let me know."

F. RELIABILITY TOOLS, TECHNIQUES AND PROCESSES

This section provides information on the methods and strategies used to implement reliability management. Data pertaining to the use of contractual incentives will be discussed along with the issues of influencing requirements, *designing-in* reliability, and test and evaluation.

1. Requirements Generation

Requirement generation is the genesis of every acquisition program. The data presented here was gathered to address the PM's ability to influence system requirements, with respect to reliability, during their initial formation. Programs were asked:

Were you as the material developer able to influence the incorporation of realistic reliability requirements as part of the ORD process?

Table 6 depicts the responses.

Ability to Influence Reliability Requirements in the ORD?	Program Responses	%
YES	9	69%
NO	2	15%
Other	1	8%

Table 6. PMs Influence on Requirement Generation

Additionally PMAs were asked whether reliability was identified as a key performance parameter (KPP). Because KPPs are those requirements or capabilities that are deemed to be so critical that failure to reach the threshold level may result in the programs termination, the researcher wanted to determine if reliability issues reached this level of scrutiny. Only four programs answered in the affirmative, with others replying that although not a KPP, reliability ranks within the highest tier of priority.

Response Summary: Overwhelmingly the programs participated in the derivation of requirements to be included in the Operational Requirements Document (ORD). The "no" votes reflect legacy programs in which a sister service acts as the executive agent and whose original requirements document cannot be located. The "other" vote is from a support equipment program that gets its requirements through the systems it supports.

However, there was not unanimity in support of the requirement process. One team leader felt that the original user requirements were altered not because of technical necessity but to merely to satisfy the desired contractor's estimates. The natural course of compromise that occurs in requirements generation is hard to quantify in terms of severity, because the consequences are not realized until some point in the future.

Supporting Comments: The following comments are paraphrased from survey questionnaire responses and interviews.

- Initial values were solicited from operational users and requirement 'gate keepers,' but were modified to meet potential contractor estimates based on financial incentives and contract award fees.
- User requirements are sometimes in need of a reality check. The reliability engineering realities do not support the uninformed user.
- If reliability experts are not integrated into the IPTs until after the ORD and contracts are developed, it will take years to correct.
- R&M is not a KPP, but is much on the minds of the PMA in relation to passing OPEVAL.

2. Design for Reliability

An ideal time to consider reliability of a system is while there are still opportunities to influence the outcome. Given a set of agreed upon requirements, programs must then translate those requirements into a functioning system. With that in mind, the survey questionnaire participants were asked:

What contractual design tools were/are employed to ensure reliability is "built in" early on in the program?

Table 7 depicts the program responses.

Types of Design Tools Used to "Design-in" Reliability Upfront in a Program	Program Responses	%
Physics of Failure (PoF)	2	15%
Critical Items List/Analysis	6	46%
Identification of Known Problem Areas	9	69%
Software Reliability Assessment	7	54%
Quality Function Deployment	1	8%
Parts Control Program	8	62%
FMECA /FRACAS /FTA	12	92%
Reliability Prediction Analysis	4	31%

Table 7. Reliability Design Tools

Response Summary: All PMAs reported using design tools to address reliability within their system. 100 percent of the programs use some form of failure analysis as an integral part of design. There was a clear consensus that employment of tools that incorporate reliability considerations into system design was required.

Additional Paraphrased Comments: The following paraphrased comments reflect the survey questionnaire responses describing additional tools:

- Specification Allocation -the [MTBF] requirement was allocated to each element of the weapon system.
- Design to Allocation - required the minimum design to allocation to be at least 25% above the specification allocation to ensure confidence in achieving specified requirements.
- Design and Fleet Field predictions were used.

- Stress analysis and stress derating were also done.
- Implemented prediction that directly correlates to other program goals and have driven contractor to that prediction.
- As reliability engineers we list all of tools that we think will be useful, knowing that PMS will cut many of them citing fiscal restraints.

3. Contracting for Reliability

Contracts and contractual incentives are often used as motivation tools or strategies attempting to focus a contractor's effort. Contracts produce a similar effect on the Government's side by concentrating attention on particular components of a given acquisition program. Several question posed in the survey questionnaire were aimed at determining how reliability requirements are interpreted into a contract.

The first contract related question:

Was reliability included as a factor in source selection?

Table 8 depicts the survey responses.

RELIABILITY AS A FACTOR IN SOURCE SELECTION		
YES	NO	UNK
6	4	3
46%	31%	23%

Table 8. Reliability in Source Selection

Response Summary: Half of the programs confirmed the use of reliability measures during source selection. These programs generally represented ACAT I high dollar programs

with large defense contractors. In general most respondents felt that issues like FMECA, FRACAS, and predictions were discussed even if not formal source selection criteria.

The second contract related question inquired about the translation of operational requirements to contractual requirements. Table 9 provides the answers to the following question:

How are ORD reliability requirements for your program translated into actual contractual reliability requirements?

TRANSLATION OF ORD RELIABILITY REQUIREMENTS TO CONTRACTUAL REQUIREMENTS	
ORD Requirement Restated in SOW	6
Additional Levels Applied to Contract	4
Reliability Not Adequately Addressed	1
Other	1

Table 9. Reliability Requirements in the Contract

Response Summary: All of the programs that have established contracts stated that at a minimum the ORD requirements were restated in the SOW. There was one dissenting comment that pertained to degradation of operational requirements being *nipped at* in small increments beginning with their translation into the contract.

Additional Paraphrased Comments:

- As part of the IPT process the contractor was tasked with developing a R&M design program that would reduce risk and demonstrate the ORD requirements.
- The R&M audit trail process dictates the process. ORD values are translated into Design Controllable numbers, with confidence bands and safety margins applied to go from ORD to TEMP to SPEC.
- Design controllable reliability requirement added to spec / ORD had value that included induced failures.
- The primary metric for assessing operating reliability of the [system] is the Captive Carry Mean Time Between Failure (MTBF). The [system] reliability is heavily dependant on the host aircraft upon which it is being employed and the corresponding environment in which the aircraft is flown.
- [System] variants have been deployed for a number of years in the USN/USAF inventory and captive carry MTBF has been determined to be the best reliability metric based on its use history. Therefore, a single MTBF number was detailed in the SOW/performance specification, which was provided to the contractor.
- New programs are putting the [reliability] issues in the contract as a means of enforcement.

Lastly, PMAs were asked:

Are there incentives employed in the contract that are specifically tied to achieving system reliability performance requirements?

Their responses are summarized in table 10.

Are Reliability Incentives Incorporated Within the Contract?	Program Responses	If Yes, Did The Incentives Achieve Their Desired Effect?		
		Y	N	Too Early to Tell
Yes	5			5
No	7			

Table 10. Reliability Contractual Incentives

Response Summary: With less than half of the programs indicating that they have incorporated incentives in the contract, there was a mixed response to this question. Some programs responded that reliability goals were achieved through IPT style supervision, rather than actual contractual incentives. None of the programs that have established reliability incentives have yet had an opportunity to evaluate effectiveness.

Additional Comments: One technical team lead, with an operational background, indicated that the incentives on his program were unfortunately misguided. He felt that the incentives shifted the focus from operational pertinent reliability requirements to ones based on contractor estimates of "achievable standards" not reflective of original agreed upon requirements. Additionally he stated:

We're 100% over budget and not meeting the early DT testing conditions. Fundamental shortfalls programmatically in design, systems engineering and simulation have produced an immature design held to financial constraints.

From the same program another respondent reported that during the design phase R&M was an Award Fee consideration, but was outranked by cost and schedule impacts. During testing reliability is being measured against its contractual requirements.

4. Reliability Test and Evaluation Activities

Test and evaluation (T&E) is an integral part of every program. T&E is undertaken both to aid in the development of a system and to verify that a given product meets the standards as stated by the customer. This data section was derived from a series of questions that addressed reliability growth programs, common understanding of reliability terms among parties, test activities, and reliability entrance criteria.

a. Reliability Growth Program

Most programs incorporate a Test-Analyze-Test-Fix (TAFT) approach to product development. An essential reliability component of TAFT is the reliability development or growth plan (RDP/RGP). Survey questionnaire respondents were asked whether their program had incorporated a RGT. Table 11 depicts the responses to the following question:

Does your program incorporate a reliability growth program?

Does Your Program Incorporate a Reliability Growth Program?	Program Responses	%	Passed Reliability Requirement in RQT or Initial OT?		
			Y	N	Did Not Have Yet
Yes	7	54		2	3
No	6	46	1		4
N/A	1	8	1		

Table 11. Incorporation of Reliability Growth Program

Response Summary: Most of the participating programs have an established reliability growth program. The “not applicable” response was from an acquisition program to

early in its life cycle to have yet established a RGP. Overall the response was mixed between the PMAs with formal growth programs and the PMAs who claim to achieve associated *reliability growth* in the natural course of development.

Additional Paraphrased Comments: The following comments are paraphrased from interview and survey respondents:

- Both the Statement of Work and the contractor's Reliability Development Growth Program Plan outline our reliability growth tests.
- In the design specification in the form of a reliability requirement to be demonstrated in a Technical Evaluation period at the end of the EMD testing prior to OPEVAL.
- No reliability growth programs although technical directives are issued to correct known deficiencies.
- Weapon systems have to grow into it [reliability].
- PMs may need to add developmental tests to achieve the required level of confidence.

b. Common Terms and Methods for Measuring Reliability

Common understanding of terms is fundamental to a mutual understanding of reliability test results. This is an issue when comparing different weapon systems (e.g. F/A-18 vs. JSF), a lack of agreement amongst cooperative partners within a program can be paralyzing. Additionally, there is a difference between how the operator/user views and measures reliability, and how reliability is measured during developmental testing within the same program. Each of the PMAs was asked:

Have the user, tester, contractor and PMO all agreed upon the method (model) to be used in reliability calculations?

Table 12 depicts the results.

Have the PM, User, Contractor, and Tester Agreed Upon the Method to be used for Measuring Reliability ?	Program Responses	%
Yes	9	69%
No	1	8%
Not Sure	3	23%

Table 12. Common Agreement on Reliability Methods

Response Summary:

Most of the responding PMAs acknowledged a positive effort to reach a common understanding. The sole "no response" was from the program that has not yet established their methods or terms. The "not sure" responses correspond to respondents who stated that they were not familiar with this particular issue because the test phase occurred years before they became involved in the program.

Additional Paraphrased Comments:

- ORD, SPEC and TEMP have standardized R&M formulas and definitions.
- The contract requirement deals with design controllable or inherent failures. To provide the fleet perspective the test data collected and scored using specific criteria, the results could be presented as to how the system is performing in terms of contract requirement and simultaneously present the expected fleet performance.
- The Joint Reliability and Maintainability Evaluation Team and Test Data Scoring Board

(JRMET/TDSB) charter documents the methods to be used.

- Captive Carry MTBF is specified in the contract.
- The NAVAIR model was agreed to and its use is stated in our reliability attachment.

c. Reliability Test Activities

Reliability testing can take many forms and the wide selection of possible techniques allows for tailoring a test program to fit a given program. The following question was aimed to determine which test activities PMAs use.

Identify the types of test activities that have or will be used to determine compliance as part of your system's reliability program.

Types of Test Activities PMs Use to Determine Reliability Performance Progress & Compliance	Program Responses	%
Environmental Testing/Stress Screening	11	85%
Accelerated Testing (e.g. HALT)	7	54%
Reliability Development Growth Test (RDGT)	6	46%
Reliability Qualification/Demonstration Test (RQ/DT)	5	38%
Government Development Test (DT)	7	54%
Operational Testing (e.g. LUT/OPTempo/IOTE/FOTE)	10	77%
Acceptance Test/Production Verification Test		
Maintenance Demonstration		

Table 13. Reliability Test Activities

Response Summary:

Programs overwhelmingly address reliability through environmental screening and operational testing.

Additionally some programs reported the use of software functional testing and stockpile reliability testing/sampling.

d. Reliability Entrance Criteria for OPEVAL

OPEVAL is the *final exam* for programs just prior to the decision on whether the system will go on to full-rate production. Given the importance of OPEVAL, and the history of programs having significant shortfalls in reliability during this phase of testing, each of the PMAs were asked about their approach to addressing this situation. [Ref.2 DOT&E, 00] Table 14 summarizes the PMA responses to the following question:

Does (or did) your program have specific OPEVAL entrance criteria relative to reliability?

Does Your Program Have Reliability Entrance Criteria for OPEVAL?	Program Responses	%
Yes	4	31%
No	5	38%
Not Sure	4	31%

Table 14. Reliability Entrance Criteria Response Summary:

Surprisingly, only one-third of the programs surveyed have established dedicated reliability entrance criteria to OPEVAL. Some of these programs have even identified entrance criteria for the earlier phase of operational assessment (OA). For example, OA entrance criteria were 25% of the OPEVAL requirement allowing for immaturity of a system in its early stage of development.

e. Early Test Results versus OPEVAL

Testing within a program occurs on a continuum beginning with early contractor testing and progressing through OPEVAL into follow-on test and evaluation. The purpose of development testing is to help mature a system and to verify that the product does indeed meet technical expectations. OPEVAL is focused on the operational effectiveness and operational suitability, and is conducted outside of the restrictive bounds of the DT environment. The PMAs were asked if the early testing related to success in OPEVAL.

If your system has already participated in OPEVAL, did your success in either DT or other reliability-testing correlate with success in OPEVAL?

Table 15 relates the program responses to OPEVAL, as well as emerging DT/OT results.

Correlation of Early Reliability Test Results with OPEVAL Results?	Program Response	%	Level of ORD Reliability Requirement Demonstrated	
			Initial DT Results	Initial OT Results
Yes, success in pre-OPEVAL reliability testing led to requirements being fully met in initial IOTE.	3	23%	100%	100%
			4	4
Not completely, system did well in early testing but had some problems in OPEVAL	2	15%	80%	80%
			1	1
Not at first, system passed OPEVAL after <u>X</u> attempts.			60%	60%
			1	
N/A, system either not yet involved in an operational test or the early testing did not assess reliability.	8	62%	< 40%	< 40%
			1	

Table 15. Correlation of Early Test Results with OPEVAL

Response Summary:

The majority of the responding programs had not yet undergone the scrutiny of OPEVAL. Those programs that had experienced OPEVAL were evenly split on their responses. Reliability success in pre-OPEVAL testing does not assure success in OPEVAL itself. Programmatic success relates to how the PMA used the information gained from the testing undertaken, and under what conditions or environment the system was tested.

Additional Paraphrased Comments: Several respondents included illustrative examples from their programs. Here are some paraphrased examples:

- Some had a combined DT/OT test (OT-IIA), which used EDM configuration hardware with encouraging results.
- In general systems that completed qualification, reliability, and flight tests then had corrective actions installed and retested did well in OPEVAL. In a number of cases, systems underwent process changes or had improvements incorporated but were not flight-tested and experienced a lot of problems in OPEVAL due to infant mortality and bad process control.
- TAFT was painful, but it seemed to work. We instituted a corrective action board that tracked identified problems and approved solutions and determined the degree of retesting required.
- The primary *lesson learned* on [system] was that a tactically operationally representative test program where the test article can be tested in the full-up configuration on the aircraft and functionally tested almost real-time is the most effective method for assessing inherent reliability and the probability of passing formal OPEVAL.

G. RELIABILITY OF FIELDDED SYSTEMS

Programs that have properly planned and executed effective reliability management plans may reap benefits once a system reaches the hands of the war fighting operators. History has shown that in practice, however, that the PMA's reliability work is not yet complete. The DoD 5000.2-R specifically charges PMs and the logistics community with supporting fielded systems. [Ref. 14]

This section seeks to provide information on how this support mission is accomplished. Only two of the thirteen programs participating in the survey questionnaire had reached the fleet fielding stage. The response summary combines those program responses with information received for additional interview subjects and respondents who answered from supervisory positions reflecting upon multiple programs.

RELIABILITY OF FIELDDED SYSTEMS				
	YES		NO	
	#	%	#	%
Conditional Materiel Release (CMR)				
Was the system initially fielded with a CMR due to reliability shortfalls?			3	
Is the CMR still in effect?				
N/A				
Collection of Field Reliability Data				
Reliability information is obtained from Depot, Contractor Logistics Support (CLS) records, or other means (e.g. Production Quality Deficiency Reports PQDRs)	4			
Warranty collection data provides information on reliability performance				
A formal collection system does not exist				
Status of Reliability in the Field				
System performance meets/exceeds ORD requirement	3			
System performance is less than ORD requirement				
Do not know (due to lack of data, or too early)				
Cost Effective Reliability Improvements				
Has collection of reliability failure data in the field led to any cost effective improvements?			3	
Too early in program to tell				
Reliability Improvement Program				
Is there a formal reliability improvement program?	2		3	
Reliability Centered Maintenance (RCM)				
Is there a formal RCM program?	4		1	

Table 16. Reliability of Fielded Systems

Response Summary: Fielded systems often are seen as the benchmark of success, but the hard work has just begun.

Ideally, the processes used to assess and enhance system reliability throughout the acquisition cycle will pay off. Compromises along the way however, have invariably taken a toll on the optimization of reliability.

Experience seems to have demonstrated that the reliability activities used in the design, development and production of a system have been geared to meet a specification requirement that may not reflect the actual operators use of the system. Programs sometimes complain that the user does not operate a system as it was designed, while operators retort that the system was not designed to be operated in the manner they require.

Disconnects between the program office and the warfighter seem to be traced to communication failures. Either, there is an actual problem with the weapon system, or with its associated training plan. Both of these items fall within the purview and responsibilities of the PM.

There is little consistency between the programs. Some systems state reliability in different ways. Here are three weapon system examples: 1) The weapons will be at least XX% reliable when removed from its container at any time during its life; 2) The weapons will be least XX% reliable when removed from it container after five years in storage or 3) Weapons must be at least XX% reliable when tested after three years and may degrade no more the Y% for each additional year. Other systems state the requirement in terms of Storage MTBF, Captive Carry MTBF or both.

The collection of field data is a crucial element in reliability support. Aircraft systems generally provide maintenance information through automated information

systems. Naval Aviation Logistics Command Management Information System (NALCOMIS) collects and provides automation for organizational and intermediate level maintenance activities. NALCOMIS is generally used as a day-to-day management tool and holds maintenance related information including historical logs and records. [Ref. 29]

The need for improved data analysis, resulting from the growth in sophistication and complexity of weapon systems, has led to the development of the Naval Aviation Logistics Data Analysis (NALDA) System. [Ref. 36] However, reliability practitioners feel that this system provides a wealth of data but does not directly correlate to reliability uses. NAVAIR does have at least three activities, in varying stages of implementation, focused on *in-service* management that incorporates reliability. The three activities are Reliability Centered Maintenance (RCM), Sustained Maintenance Planning (SMP), and Reliability Improvement Teams located at the depots.

RCM is an analytical process used to determine preventive maintenance (PM) requirements. Used as a tactic, RCM is a strategy that is function oriented seeking to preserve system functions through maintenance at failure, preventive maintenance, predictive maintenance and detective maintenance. The basic fundamental of RCM is the root cause analysis of why a failure occurred. The root cause needs to be determined so that an appropriate solution can be invoked. [Ref. 21]

SMP and RIT both stem from the Business Process Review (BPR) initiative. SMP aims not only at identifying

problems but also attempts to examine proactive opportunities to infuse new technologies, obsolescence avoidance, and maintenance improvements encompassing additional perspectives beyond reliability. SMP implementation has been program specific vice a centralized NAVAIR process.

The reliability improvement teams look to improve component reliability and lower life cycle costs through the identification of high cost and/or low reliability items. Once the components are identified, processes and results from maintenance and repair are studied to identify improvements. The intent is to complete a full loop from problem identification, fix implementation, through solution verification. Their reliability analysis model is currently in its initial phase with a low-tech approach. Figure 8 depicts the three-phased development of the program.

Supporting Comments:

- TAFT was painful, but success was in the fielding.
- Most systems do employ RCM, but "hands-on" data collection and scrubbing is very inefficient and labor intensive.
- No extensive reliability data collection system available. No S/N tie to failure data for O/I/D level life cycle tracking - NEED ONE ! We're "data rich - info poor".
- Need to identify reliability data collection goals (time on wing, rework requirements, MP support, RCM/PM reqts, etc.) and develop the data collection system to support those goals.
- While real time supply support is certainly a plus, have concerns with TLS contracts in regards to prime "preaching" reliability improvements,

stating irrelevant metrics, and not producing improvements.

- RCM for weapons is still a work in progress. Weapons reliability is driven by electronics random failure; this failure mechanism is not suited to RCM.



Reliability Analysis Model

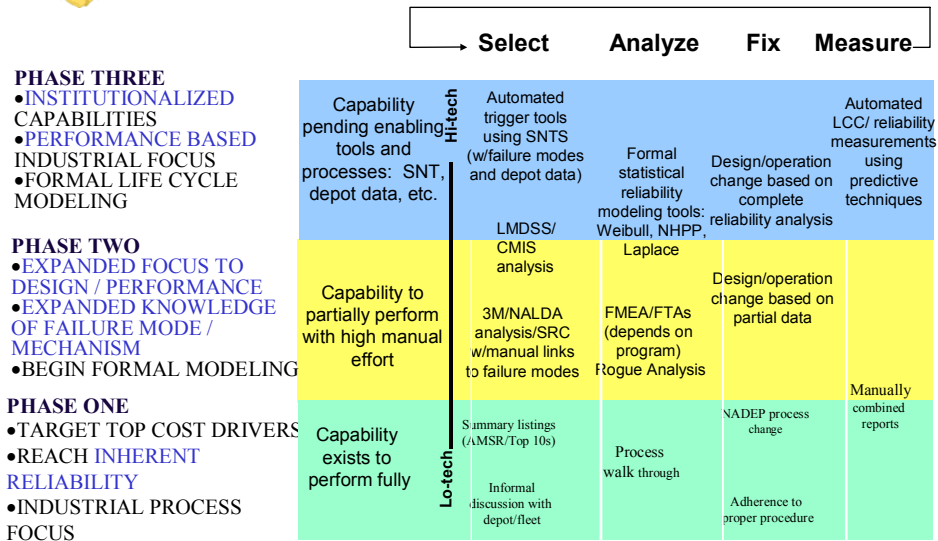


Figure 7. Business Process Review Reliability Analysis Model [From Ref.4]

H. AFFECTS OF ACQUISITION REFORM

Acquisition reform is a leadership-sponsored movement throughout the Department of Defense endeavoring to make the acquisition process more effective, efficient and productive. The reform initiative is intended to streamline requirements and reduce the system's cycle time. Moves toward the use of commercial practices and private enterprise are hallmarks of Acquisition reform.

On June 29, 1994, Department of Defense Secretary William Perry mandated the use of acquisition reform throughout DoD with the issuance of his memorandum entitled, "Specifications and Standards--A New Way of Doing Business." The implementation of streamlining measures and personnel reductions had effects throughout the acquisition community. The researcher sought to determine the perceived effects of reform on the engineering discipline of reliability and its management. [Ref. 23]

Survey questionnaire participants were asked:

In your opinion, has acquisition streamlining (e.g. performance specifications, use of COTS, etc..) and/or the continued trend of government downsizing contributed either directly or indirectly towards reliability shortfalls experienced by programs?

Additionally, two follow-up questions are included in Table 17 and the response summary below;

a) If COTS/NDI components were/are utilized in the design of your system, did the COTS components realize the reliability performance claims of the OEM? b) Given the realities of streamlining and downsizing, do you believe the Navy reliability community has adequately compensated with alternative policies, processes and tools?

In your opinion, has the move towards performance-based specifications, the increased use of COTS, and/or the continued trend of Government downsizing had any negative effects on reliability of systems?	Program Responses	% of Programs
Yes, due to performance based specifications.	4	31%
Yes, due to downsizing the workforce.		.
Yes, due to both acquisition streamlining and downsizing	5	38%
No	2	15%
No comment	4	31%
COTS/NDI components do not live up to OEM claims	3	23%

Table 17. Effects of Acquisition Reform Initiatives

Response Summary:

Respondents and interviewees generally expressed concern that although acquisition reform has benefited some areas, reliability practices and reliability management have specifically been hampered. The combination of a reduction in the reliability workforce and increased use of commercial of the shelf (COTS) items continually were highlighted as problem areas.

The reliability workforce has declined while the increased use of commercial items and performance specifications actually has increased the total workload. COTS usage has proven to be more work than it appears because COTS equipment has not been designed to operate in the warfighters environment.

Additional Paraphrased Comments:

- The perception by program offices is that all you have to do with COTS is install it—no need to test.

- COTS has major limitations and upper management does not understand this or even want to discuss it.
- Programs have found that on COTS where they did HALT testing, they improved the system and expect it these systems to work in our environment.
- PMs need to determine if COTS items will survive in your operating environment.
- Contractors have stated that are *going to* commercial components and that we have to change our environmental requirements, as their systems will no longer meet the existing standards.
- When some PMAs receive a request to use COTS or commercial components in a design, they require HALT.
- Some programs use COTS but always have to harden them to work in our environs—so are they still COTS?
- The reduced use of specs and standards has hampered our effectiveness.
- Streamlining means the use of COTS, less people to track R&M, less people to follow up and fix issues.
- Reliability personnel cuts led to the current method of monitoring results from the Fleet, which is too long to provide any meaningful feedback to the manufacturer to help in reliability growth. Systems are out of warranty before they are evaluated for reliability..
- Ignorance is not an acceptable solution to inadequately funded/resourced effort. Additional risk not only kills programs, it kills people and combat effectiveness.

Paraphrased Respondent Suggestions: Survey questionnaire respondents were asked if they had suggestions for improvement to acquisition reform. Selected comments are listed below:

- Mandate the use of life-cycle-costs as the basis for all design trade-offs. Currently the unit production cost is used, therefore reliability and life-cycle-costs are always sacrificed to produce a lower unit cost. The unit cost is generally the metric which determines the success of the program for the Milestone Decision Authority (MDA).
- Need to standardize modeling tools used within NAVAIR.
- Working with USAF; their standardization of processes are documented better.
- Do not use COTS. Use what is best to meet reliability goals of the program.
- Streamlining and downsizing, to be effective, requires all parties to assume greater responsibility. In practice we have spread so thin and not held anyone accountable. We need to empower (and reward) people to accept the additional responsibility that has been thrust upon them.
- Fund and resource to adequate levels.
- R&M and supportability are always compromised when executing programs. These activities need to be funded and their schedules need to be shielded from compression that would make them meaningless. We will pay up-front or the fleet WILL pay once it gets fielded.

All surveyed programs were asked to identify which reliability related commercial practices were employed in their program. Table 18 presents their responses.

What Types of Commercial Reliability Assurance Practices Do You Employ in Your Program?	Program Responses	%
Physics of Failure (PoF)	3	23%
Predictive Models	3	23%
Prognostics/Life Consumption Monitoring	2	15%
Identification and Mitigation of Failure Modes (FMECA)	6	46%
Accelerated Life Testing (e.g. HALT)	4	31%
Reliability Growth Testing	2	15%
Reliability-Driven Parts Selection/Control	3	23%
Other	3	23%
Do Not Employ any Commercial Practices	3	23%

Table 18. Commercial Reliability Practices

Response Summary:

Commercial practices are widely used in Naval aviation programs. Programs tailor the practices employed to fit their reliability goals and more importantly their budget.

Additional Paraphrased Comments:

- Need to benchmark some commercial systems (believe Northwest has an efficient data collection/analysis system).
- Our practices are reactive programatics, not a deliberate effort to effectively mitigate risks.

I. CHAPTER SUMMARY

This chapter presented the methodology used and the data gathered relating to the task of reliability management. Acquisition workforce professionals directly contributed through participation in either interviews and/or completion of a survey styled questionnaire. The information provided reflects the experience and perceptions of the experts who know the issues involved

with reliability management. The data was organized in four categories: 1) Reliability Management Environment; 2) Reliability Processes and Tools; 3) Reliability of Fielded Systems; and 4) Affects of Acquisition Reform.

Chapter IV provides an organized analysis of the data presented in this chapter, focusing on the methods available to the PM to optimize reliability.

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IV. ANALYSIS OF RELIABILITY MANAGEMENT

A. INTRODUCTION

This chapter discusses the results of research and the data presented in Chapters II and III. The focus of analysis is on the primary thesis question:

"What strategies should Program Managers implement to optimize reliability in their weapon system?"

The qualitative analysis presented will follow the format of the data presented in the previous chapter, including the following four themed categories: 1) Reliability Management Environment; 2) Reliability Tools, Techniques and Processes; 3) Reliability of Fielded Systems; 4) Affects of Acquisition Reform.

B. RELIABILITY MANAGEMENT ENVIRONMENT

1. Reliability Responsibility

The Program Manager is ultimately responsible for reliability, and the reliability results achieved will reflect the PMs attention to the issue. Tailoring may account for some differences between programs but if individuals within the same program cannot identify the body responsible for reliability management there is a significant lack of leadership attention to the subject.

Although it may seem logical that an IPT created to deal with program reliability issues would have primary responsibility of its management, it also can be perceived as a stovepipe or constricting process. The programs that assigned the reliability members to each design team claim to have done so with purpose. Through the dissemination of

reliability expertise these programs aim to catch problematic issues before they are instituted. This forward thinking approach displays an attitude toward reliability that shifts its management from supervisory to participatory.

Even with logistical and reliability personnel disseminated throughout a program there should still be a recognizable champion for reliability issues. On programs where there is not a consistent designated reliability authority there may be a lack of focus to the subject.

2. Reliability Documentation

The data shows that documenting reliability on a program level is accomplished most often through the use of a dedicated Reliability Program Plan (RPP). Although programs have developed a document detailing the activities and responsibilities surrounding the management of reliability, it should be noted that none of the programs provided their RPP to the researcher. Therefore a thorough analysis of the contents of these plans was not possible. Review of these documents is warranted and is listed in Chapter V as an area for further research. It is critical that PMAs have reliability criteria that is clear and can be rigorously enforced.

3. Reliability Resources

Acquisition management is accomplished in a fiscal reality where resources are limited and *true* costs are not articulated. As such, any analysis done must appreciate the *gray area* of the political arena in which PMs operate. It is not that limited resources applied to reliability cannot be explained or appreciated, but the acquisition community and its leadership must knowingly acknowledge

that money not spent on reliability optimization during development will be spent many times over during operations and support.

This fiscal *death spiral* is where the services currently find themselves attempting to maintain a legacy system laden defense force. Although current budgeting events surrounding the *War on Terrorism* are likely to yield positive increases in recapitalization funding, if those recapitalization efforts do not reflect reliability improvement measures there will have been no *learning* from the fleets present condition and existing systems will continue their downward slide.

The competition for funding that pits reliability improvements against performance enhancements is foreboding. Often the system performance improvements are made not only at the expense of possible reliability enhancements, but actually further degrade the existing reliability. The lack of emphasis on reliability resources is counterproductive to any life cycle concern.

4. Reliability Regulations and Policies

The current state of regulatory documents and policies seems insufficient for use as constructive managerial tools. Although the advent of the *Spec and Standards Reform* does allow great latitude for PMs to tailor and apply commercial standards to suit their needs, the commercial standards for reliability do not reflect the reliability needs of DoD. In practice, programs continue to use the cancelled specs and standards through a *cut and paste* mentality placing the MIL-SPEC information in the Statement of Work.

Some might contend that this approach is perfectly aligned with the reform movement, which allows the use of Government standards where required. However, the Government reliability standards are no longer reviewed or maintained on a regular basis. Despite the efforts of the Reliability Research Center no commercial standard exists for reliability engineering or management.

The pending rewrite of the SECNAVINST 5000.2C has reliability specific guidance that should be a useful aid to PMs. A consistent recognition of, and focus upon, the importance of reliability management will greatly benefit the life cycle cost burden under which our current systems suffer. The acquisition workforce personnel responsible for reliability, including the logisticians, engineers and testers, require enforceable criteria and clearly delineated reliability management fundamental procedures.

C. RELIABILITY TOOLS, TECHNIQUES AND PROCESSES

1. Requirements Generation

The data shows that PMAs are involved in the reliability requirement generation in most cases. PMA involvement implies an opportunity for PMs to have a positive influence on the incorporation of realistic reliability requirements. The extent to which this positive influence is effective is reflective of reliability and logistical experts level of involvement and their understanding of the criticality of reliability.

It is essential that the logisticians and reliability personnel be involved in this early stage of the program development. The issue of reliability truly should be

multi-disciplinary and cannot be relegated to the engineering disciplines. Reliability is a fundamental component of a systems development and requires input from all sources. A reliability oversight during requirements generation can take years to fix and is difficult to incorporate into an existing program.

2. Design for Reliability

Design emphasis must reflect the required reliability and robustness required by the warfighter's operational environment. The PM, using the Systems Engineering Process with strong input from logistics management, is responsible for taking validated user requirements and turning them into design criteria. A balance must be struck between cost, schedule, performance, risk and life cycle needs. Reliability certainly falls within this purview.

It is up to the PMA to exploit opportunities to design for reliability, manufacturability and overall producibility. Unlike the PM, the warfighters and user representatives are not likely familiar with these concerns. They will concentrate on performance figures and production numbers. Concepts like simplicity of design must be presented in terms of increased reliability, maintainability and operational availability. Each of the system's parts is in effect a building block with inherent reliability.

Each of the participating programs reported the use of design tools that address reliability. The effectiveness of these tools is of course to be determined over time with each systems usage. But the acknowledgement of the need

for reliability enhancing tools in system design is a good thing.

3. Contracting for Reliability

If it is important put it in the contract. To influence reliability design requirements, the contract must articulate their importance. Motivation articulated through incentives is an effective strategy encouraging contractors to apply their best efforts on the issue.

Contractual reliability incentive usage within the participating programs is encouraging. Although less than half of the programs report the usage of incentives, the programs that have implemented incentives appear to have *learned the lesson*. Their usage of award fees to focus the contractor's efforts on reliability improvement is a positive step toward optimization of reliability.

Overall, PMAs must realize that realize that many areas affect reliability and that participation with the contractor during system design is essential. To influence design—put it in the contract and monitor contractor compliance. Only through vigorous involvement can the PMA ensure and enforce the contractors focus on reliability.

4. Reliability Test and Evaluation Activities

There is a consistent cultural conflict between the test community and the PM shop. However, test and evaluation (T&E) is an integral part of every program. T&E is undertaken both to aid in the development of a system and to verify that a given product meets the standards as stated by the customer. The respondent and interview comments indicate that PMAs generally think that some testers test to unrealistic mature reliability thresholds

before a system is allowed to mature, and do not have an appreciation for when the user needs are met.

A defined reliability growth program is a helpful tool to help articulate the PM point of view. A realistic growth strategy that develops as the product itself grows is prudent and would be useful to testers and decision makers alike. The growth of system reliability cannot be taken for granted and must be consistently monitored and tested to ensure compliance with the user's needs. Additional tests may be required either to verify product improvements or simply to obtain a reasonable confidence level in the system's results.

Although there is PMA appreciation for the risk that not meeting reliability requirements poses to a program, there is not a consistent pattern of risk management applied to reliability management. Tailoring may again rightfully address why there is not a uniform set of procedures used to test reliability, but does not address the perception that the lack of reliability testing is knowingly accepted because of an unwillingness of PMs to receive bad news or accept schedule required adjustments.

PM use of realistic reliability entrance criteria to stages of testing including OPEVAL, and having clearly articulated reliability KPPs are effective management tools and would help establish required reliability thresholds for which programs could strive. A tailored selection of environmental and accelerated tests combined with an effective failure reporting system that incorporates corrective actions could be used to demonstrate a program's seriousness when addressing reliability. Experience

continues to demonstrate that it does little good to complete testing but fail to act upon the knowledge gained.

A null hypothesis must be applied to vendor and program claims of MTBF levels. The testers and PMAs must demand proof that a product will indeed perform in the DoD application to the claimed level. This testing must be accomplished with a level of confidence that allows decision makers to make informed judgments about a system's production and support requirements.

D. RELIABILITY OF FIELDDED SYSTEMS

Success is too often believed to have occurred upon reaching a full rate production decision or upon initial fielding. Even when the war fighting units have been fully outfitted, program management work remains. Weapon systems and their logistic support structure must be carefully monitored, measured, and adjusted as appropriate.

Collection of field reliability performance data is not uniform and hard to accomplish. Warfighters are more concerned with performance measures than with logistical concerns, until there is a problem. Once a problematic situation has risen to the attention of the fleet user the PMS job has gotten harder. Programs that rely upon reactive means for identifying and correcting problems will terminally be on the defensive.

Proactive measures pay dividends in terms of the fleet's Operational Availability (Ao). However, those proactive programs do not come without a cost. Resources in the form of time, money and technology must be spent to collect in-service equipment data. Additional resources

must then be applied to identify and implement corrective actions as required. Unfortunately, logistical support of fielded systems is funded with operational support dollars and often insufficient to permit reliability improvements.

Centrally collected data needs to be formulated in a manner that usefully reflects system reliability. This data should be evaluated and acted upon. The addition of a specific Flag-level reliability review would highlight the importance of reliability, and could improve the situation if the data is formulated as value added information. If the acquisition and operational leadership is truly concerned with reliability as a life cycle cost driver their actions would speak volumes versus toothless statements placed within strategic plans.

E. EFFECT OF ACQUISITION REFORM

Three by-products of acquisition reform were cited as having negative effects on reliability of systems. First, the implementation of performance based specifications replacing the Government standards that dictated reliability practices; Second, the reduction in the reliability workforce combined with streamlining; Third, the misuse or misunderstanding of commercial-off-the-shelf (COTS) items.

The shift away from Government documents towards commercial practices and industry standards certainly has had merit in some areas. However, the general perception from the reliability duty experts was that no industry standard exists and that there is yet to be any gain from the use of commercial practices. There are encouraging

areas, such as the increased application of HALT, but no consistent standards from which to measure.

The significance of the workforce reduction is amplified when it is combined with the increased use of COTS. COTS items are too often thought of as a quick and easy bolt on fix that requires little or no testing. In reality, COTS items have not been designed for the warfighting environment and require reliability testing to ensure their success in the DoD application. If a COTS item is then found to be lacking, appropriate modifications must be made in order to meet the user's needs.

The mentality toward COTS that "it already works, that's why we are buying it" is ill informed and unwise. The commercial environment seldom demands the life expectancy too which DoD has become accustomed. It has become common for DoD systems to be stretched beyond their initial service lives, which generally were longer than most businesses keep their capital equipment. COTS usage can provide substantial benefits to DoD acquisition, but the COTS application must fit the requirement, the reverse is unacceptable.

F. CHAPTER SUMMARY

Program and reliability management personnel are charged with the responsibility of fielding reliable equipment to the nation's warfighters and should be held accountable for that mission's accomplishment. This chapter provided an analysis of the reliability related data presented in the previous chapters. Chapter V will

present synopsised answers to the research question and selected conclusions and recommendations.

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V. CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

The goal of this thesis was to provide strategic planners with insight collected from the experience of acquisition workforce professionals familiar with the issues relating to reliability management. Application of the cumulative empirical evidence of these professionals permits a forward leaning proactive approach to the optimization of reliability within Department of Defense (DoD) acquisition programs.

B. ANSWERS TO RESEARCH QUESTIONS

Synopsized answers to the research question are provided here. Additional insight and information have been provided in Chapters II and IV.

1. What Strategies Should Program Managers Implement to Optimize Reliability in Their Weapon System?

Communicate and champion the optimization of reliability. It is human nature to cultivate the areas where one is held accountable.

Ensure requirements are grounded in reality and articulate reliability concerns early and often.

Embrace testing as a value added dynamic. Use all test and evaluation opportunities as learning and verification tools justifying required resources. Apply test results to improve the system. Problems identified through testing (even if they are only a matter of perception) already exist and would have been found

eventually. Treat those identified problems as knowledge gained.

Assume the null hypothesis that the contractors' reliability claims are flawed until proven otherwise. This does not predetermine an adversarial relationship with a contractor but clearly articulates the Government's position from the start.

Optimize trade-offs with respect to reliability and fully appreciate the cause and effect relationship decisions today will have on the fleet tomorrow.

Build a team of professionals skilled and educated on issues of reliability so that they may permeate the program articulating and implementing a sound acquisition strategy reflective of life cycle concerns.

2. What is Reliability and What is its Significance within Acquisition Management?

Reliability is the probability an item will perform its intended functions for a specified period under stated conditions.

Reliability is the fundamental building block that supports the warfighter. It directly supports the operational availability of systems and is the significant driver of life cycle costs. System logistical support is based upon the expected component and total system reliabilities. Poor reliability or inaccurate estimates of reliability significantly increase life cycle costs and affects every aspect of logistics elements.

3. What Policies and Regulations Governing Reliability Management are Available to Program Managers (PM)?

DoD 5000.2-R is the overarching regulatory document requiring Program Managers to establish and execute reliability activities and measurable requirements within their acquisition programs. However, since the issuance of the Secretary Perry's memo on specifications and standards reform most of the guidance on reliability has purposely become vague. Therefore there are no governing documents that provide procedural guidance to the Program Managers.

In their absence the managers, and engineers responsible for reliability, use a number of discretionary guides from the Defense Systems Management College, 'toolkits' from the Reliability Analysis Center, and the cancelled reliability military specs and handbooks. The draft copy of the SECNAVINST 5000.2C reportedly makes the most significant advance in the area of R&M since the advent of acquisition reform. Hopefully its release will regain some of the reliability ground lost.

4. What Significant Factors Contribute to Weapon System Reliability?

First and foremost system reliability stems from command attention. In terms of product development, the design process and requirements generation phases provide the critical reliability foundation. Following a credible design, the development and manufacturing processes must be formulated and adjusted to enhance the inherent reliability of the product being produced. A proactive reliability plan combined with applied lessons learned from testing

iterations will significantly enhance the opportunity for a reliable system success.

Additionally, the use of contractual incentives, KPPs, and entrance criteria linked to reliability thresholds will help raise the level of effort applied to the life cycle cost driver; reliability.

5. What Strategies are Currently Used to Monitor Reliability within an Acquisition Program?

The research identified no uniform strategy specifically aimed at monitoring reliability. Programs use a variety of methods to track reliability including reliability program plans, reliability integrated product teams, major program reviews, developmental and operational test reports. Additionally, some programs have incorporated semi-annual reliability meetings or reports and encourage three to six month reliability reviews on field equipment.

6. How can the Program Office Mitigate Risk Associated with Reliability Throughout the Acquisition Life Cycle?

Understand and articulate the significance of reliability with respect to life cycle costs and its affect on the warfighter.

Review policies, actions and decisions through the eyes of the warfighter with respect to reliability and operational availability; take corrective action as required and recognize and reward successes when they occur.

Develop and enforce a means to measure and evaluate performance as it relates to reliability. This applies throughout the life cycle inclusive of fielded systems. For systems in development use of real-world test conditions and large enough sample sizes for high confidence statements is required.

C. CONCLUSIONS AND RECOMMENDATIONS

In addition to answering the research questions, this thesis has lead to the following highlighted topics: 1) Reliability Management Culture; 2) Reliability Test and Evaluation; 3) Reliability Standards. Each of these topics is presented with a conclusion and a corresponding recommendation.

1. Reliability Management Culture

Conclusion:

Reliability management exists in an environment that does not recognize its value or reward its successes.

PMS are evaluated solely on cost, schedule and performance in the production arena. Unfortunately, reliability optimization costs both in terms of budget and time, and reliability is generally not regarded as a performance item. Conceptually the acquisition workforce recognizes reliability as a significant issue but it is lost in the crisis management atmosphere that encompasses under funded acquisition management.

There is no effective champion for reliability issues. Admittedly, the Defense Department is not designed for efficiency but rather works on a system of checks and

balances and under funded budgeting practices. However, the acknowledgement of reliability as a life cycle cost driver warrants the implementation of proactive measures.

Recommendation:

DoD/DoN leadership should develop a performance measure and reward structure that acknowledges life cycle support equal to or higher to the current cost, schedule and performance system.

Cultural change is required. A reliability and life cycle focused education must be incorporated into the acquisition workforce profession. Specific reliability attention must be given to the PM and the logistician profession.

A champion for reliability must emerge. Consideration should be given to a flag level position of a Reliability CZAR.

Additionally, the Defense Acquisition Executive Summary (DAES), which requires Program Managers to address cost, schedule, and performance, should also include Operational Availability (A_0). The fourth dimension of availability should mandate an A_0 level identifying the agreed upon target.

2. Reliability Test and Evaluation

Conclusion:

The relationship between program management and test and evaluation personnel is often adversarial beyond independence.

Testing is truly a value added event that is required for effective reliability management. However, the current bounds of the PPBS and the zero defect mentality that many programs face does not encourage testing. Often decision points and funding sources are inflexible leading PMs to compress or cut testing to inadequate levels.

Recommendation:

DoD/DoN leadership should reevaluate the rigidity that exists in our funding and decision cycles and encourage a knowledge gained approach to testing.

PMs need to embrace the lessons learned through testing and allow the corrective actions to be retested to ensure the desired results have been obtained. If the negative connotation of "failing" a DT test is prevalent then we have missed the entire learning point of trying to improve the system.

Developmental testers should be integrated into the development team and not relegated to messenger duty when problems or issues arise. DT should be the PMs truth finder concerning reliability claims.

3. Reliability Standards

Conclusion:

The discipline of reliability continues to depend on the outdated cancelled MIL-STDs.

The era of dominant military standards ended with the implementation of specification and standard reform. Although these standards continue to provide helpful information they are no longer updated or reviewed. No

commercial standard has emerged to replace the Government's.

Recommendation:

DoD/DoN should work with commercial and industry sources to develop a comprehensive standard encompassing reliability management practices from a life cycle cost perspective that would be interdisciplinary in nature and applicable to the PM, reliability engineer, logistician, operational and developmental testers alike.

D. AREAS FOR FURTHER STUDY

1. Reliability Program Plan

Research in this area should examine and analyze existing PMA Reliability Program Plans. While many programs have established plans, none were provided to this researcher. Plans should be reviewed for content and degree of compliance in program execution.

2. Reliability Management in Other DoD Programs

Future research should analyze methods used in other areas of DoD acquisition. This thesis concentrated on Naval Aviation programs limiting the scope and focus. Similar analysis should be applied to other acquisition areas in order to identify any stove piped lessons learned. Additionally, comparative research can be applied to reliability management throughout the differing services or acquisition management areas within a service.

3. Reliability Management in Commercial Aviation Programs

Future research should examine reliability management and practices used in commercial aviation program management. Commercial aviation not only has experience in

producing reliable equipment but in its in-service operation as well. Lessons learned should be collected and examined for possible applicability to DoD application.

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APPENDIX A. WEAPON SYSTEM RELIABILITY PERFORMANCE SURVEY

Directions: *This survey is being conducted to support research as part of a Naval Postgraduate School Thesis on challenges in managing weapon system reliability performance. The results of this thesis are intended to directly benefit any PM that is, or will be managing complex programs, by identifying common reliability management issues and potential pitfalls, why they occur, risk mitigation techniques, lessons learned, and suggestions for improved methods for managing and reducing the inherent risks associated with achieving stated reliability performance requirements.*

The research is limited to a cross-section of systems in various stages of the acquisition process that are managed within the Naval Air Systems Command. The analysis is limited to an assessment of reliability management and process issues, and does not specifically address commodity or technology driven reliability problems.

*Please answer the following questions and email them back **NLT 01 Feb 2002**. A separate survey is required to be filled out for each participating program.*

e-mail: glmasiel@nps.navy.mil

**** Results will be represented in aggregate form, not program specific ****

Project/Program Management Office:select here (*click on dropdown list*)
(or fill in appropriate title)

Program/System Name:select here (*click on dropdown list*)
(or fill in appropriate title)

Current Life Cycle Phase:

Old 5000

- Phase 0 (CE)
- Phase I (PDRR)
- Phase II (EMD specify prior to or post LRIP)
- Phase III (Specify if prior to or post IOC-if post IOC how long has it been in the field? years)

New 5000

- MS A (specify CE or CAD)
- MS B (specify SI or SDD)
- MS C (specify LRIP or FRP)
- Operations & Support (how long has it been in the field? years)
- Other or N/A ()

Required Reliability/Availability: (specify reliability requirement/measure in terms of MTBF, MTBCMF, MTBOMF, MTBMA, A₀, etc...)

- ORD (state value e.g. 300 hrs MTBF, 95% A₀)
- Contract (state value)
- Other (state value)

Measured Reliability/Availability: (quantify measured reliability results consistent with measures/units from above, e.g. 300 hrs MTBF, 95% A₀)

- DT results: Passed? Y N
- RQT/RDGT results: Passed? Y N
- OT results: Passed? Y N
- Field Data results: (how collected:)
- Contractor claims :
- Other results: Passed? Y N
(state type of test:)

Has the system experienced any major reliability test failures? (i.e. failed DT or IOTE reliability performance requirements) Yes No

Explain:

Survey Respondent's Billet (Optional)

Please answer the following survey questions.

Survey Questions: (please answer all questions. If a question does not apply to your program due to its current acquisition phase, please answer based on experiences encountered in prior phases. Check all boxes that apply. I have left room after each question for additional commentary if you find it necessary)

1. How is the system reliability program and corresponding management approach to such formally documented within your program? (check only the primary overriding document)

Reliability Program Plan Contract SOW TEMP SAMP (SingleAcqMgmtPlan

No formal reliability management plan Other (explain:)

Additional comments:

2. Who within your organization is primarily responsible for reliability activities for this particular program? (check only one)

PM
 Project Leader
 Systems Engineering Team Lead
 Logistics/Supportability Team Lead
 Test Team Lead
 Reliability IPT (formally chartered IPT? Y N
 Prime Contractor
 No one specifically
 Other (please explain)

Additional comments:

3. What contractual design tools were/are employed to ensure reliability is "built in" early on in the program? (check all that apply)

Physics of Failure (POF) techniques
 Critical Items List/Analysis (i.e. complex, state-of-the-art technology, high cost, single source, or single failure point component)
 Identification of potential reliability problems (i.e. known reliability problem areas)
 Software Reliability Assessment
 Quality Function Deployment (explain:)
 Parts Control Program
 FMECA, FRACAS, Fault Tree Analysis
 Other (describe:)

Additional comments:

4. Identify the types of test activities that have or will be used to determine compliance as part of your system's reliability program. (check all that apply)

Environmental Testing
 Accelerated Testing (e.g. HALT)
 Reliability Development Growth Test (RDGT)
 Reliability Qualification/Demonstration Test (RQT or RDT)
 Government Developmental Testing
 Operational Testing (type, i.e. LUT/OPTempo/IOT/FOT)
 Other (describe:)

Additional comments:

5. Is the amount of time and funding allotted for reliability testing during DT sufficient for your program? (for systems beyond DT, answer in terms of how your program was postured going into DT at the time)

Current schedule and available funds are sufficient (low risk

now)

Could use more time/\$\$ to reduce risk (medium/high risk now)

No comment

Additional comments:

6. Does your program incorporate a reliability growth program?

Yes (where is this detailed?)

No

N/A (check this only if system is already fielded and there are no current plans for improving the inherent system reliability)

Additional comments:

7. If your system has already participated in an OPEVAL, did your success in either DT or RD/GT (or other reliability testing) correlate with success in IOTE? (check all that apply)

Yes, success in pre-OPEVAL reliability testing led to reliability requirements being fully met in OPEVAL

Not completely, system did well in pre-OPEVAL reliability testing, but had some new problems during OPEVAL that needed correcting

Not at first, system passed OPEVAL after # attempts (click on dropdown list)

N/A, system has not yet been involved in an operational test

Additional comments:

a. To what level was your system's ORD reliability requirement demonstrated (state in terms of % of ORD requirement met)

During DT?

100%

>80%

>60%

>40%

>20%

<20%

During OT?

100%

>80%

>60%

>40%

>20%

<20%

8. Does (or did) your program have specific OPEVAL entrance criteria relative to reliability?

Yes (provide details:)

No

Additional comments:

9. Have the User, Tester, Contractor, and PMO all agreed upon the method (model) to be used in reliability calculations?

- Yes (where is this documented, e.g. contract, TEMP, SEP??)
 No
 Not sure

Additional comments:

10. Is Reliability identified as a Key Performance Parameter (KPP) in the system Operational Requirements Document?

- Yes
 No

a. If not a KPP, for systems still in development, where is reliability ranked in terms of requirements? (Relative priority)

- Highest tier priority (Band A)
 Middle tier priority (Band B)
 Lower tier (Band C or below)

Additional comments:

11. Were you as the Material Developer able to influence incorporation of realistic reliability requirements as part of the ORD process??

- No, OPNAV N78 developed requirements independently
 Yes, input was provided and included part of IPT process
 Other (explain:)

Additional comments:

12. Was reliability included as a factor in the source selection process?

- Yes (*provide details*) Was it a significant discriminator? Y N

No

Additional comments:

a. How are ORD reliability requirements for your program translated into actual contractual reliability requirements? (base on last contract awarded)

- ORD paragraphs relative to reliability are restated in SOW/Spec (*i.e. contract requirement is equal to ORD requirement*)
 Additional levels of reliability are applied to the contract (*briefly describe process*)
 Comprehensive reliability requirements are not adequately stated in the contract
 Other (*explain:*)

13. Are there incentives employed in the contract that are specifically tied to achieving system reliability performance requirements?

- Yes (*describe:*)
 No

a. If yes, did these incentives achieve their desired effect?

- Yes
 No
 Too early to tell

Additional comments:

14. Are you aware of any specific DoD or Navy policy/regulation regarding weapon system reliability management?

- Yes (if yes, which do you use to help you manage reliability?)
 No
 Not sure

Additional comments:

15. What risk mitigation techniques does your program employ that address system reliability performance issues?

Briefly describe:

Additional comments:

16. How do you measure and track reliability performance progress over time in your program? (check all that apply)

- By contractor projections/analysis
 Reliability growth tracking methodology
 At major reviews (PDR, CDR, TRRs, etc...)
 Other (please specify:)

Additional comments:

17. In your opinion, has acquisition streamlining (e.g. performance specifications, use of COTS, etc...) and/or the continued trend of government downsizing contributed either directly or indirectly towards reliability shortfalls experienced by programs in general?

- Yes, acquisition streamlining (provide details:
 Yes, government downsizing (provide details:
 Yes, both (provide details:
 No
 No comment

a. If COTS/NDI components were/are utilized in the design of your system, did the COTS components realize the reliability performance claims of the OEM?

- Met
 Exceeded
 Less (provide details, e.g. problems with integration, use in military environment, improper claims, etc... :)
 N/A (no COTS/NDI in system design)

Additional comments:

b. Given the realities of streamlining and downsizing, do you believe the Navy reliability community has adequately compensated with alternative policies, processes and tools?

- Yes
 No
 No comment

c. Do you have any suggestions for improvement? (explain:)

Additional comments:

18. For "fielded" systems only, please answer the following:

a. Was or is your program fielded in a "conditional materiel release" status due in part from failure to meet ORD RAM requirements?

Yes (*is CMR still in effect?* Yes No)

No

Additional comments:

b. How is collection of reliability field data performed to gather failure and repair histories?

Depot or CLS Maintenance records

Warranty data gives us this information

Reliability data not formally collected

Other (*explain:*)

c. Does current field reliability data indicate your system still meets or exceeds the ORD reliability requirement?

Yes

No

Reliability data not formally collected

Additional comments:

d. Has any of the reliability failure data collected led to identification of O&S cost drivers that subsequently led to cost effective improvements?

Yes (*if significant improvements, please expand upon:*)

No

Additional comments:

e. Is there a formal reliability improvement program for your system?

Yes (*if yes, where documented?*)

No

Additional comments:

f. Does your system employ a Reliability Centered Maintenance program?

Yes (*if yes, how is it formally implemented?*)

No

Additional comments:

19. Does your program employ or leverage any commercial best practices in terms of reliability performance management? (*e.g. physics of failure, predictive technologies, prognostics/life consumption monitoring, identification and mitigation of failure modes/mechanisms (FMECA), accelerated life testing, growth testing, selection of reliable parts*)

Yes (*identify:*)

No

Additional comments:

20. Rank order the following reliability management problems:

(click on dropdown list for each)

Reliability is not a KPP
Contractor not designing for reliability sufficiently above
requirement
Contractors not using best commercial practices
Not aggressively "designing-in" reliability upfront
Poor reliability planning and growth planning (test too late)
Inadequate policies and guidance (need updating)
Insufficient reliability testing to verify requirements
Unrealistic reliability requirements with inadequate rationale
Need more qualified personnel in reliability management
Not consistently improving reliability after fielding
Other (*fill in your own:*)

Additional comments:

Please provide any other comments, observations, or lessons learned
that you would like to share here (use additional sheet if necessary:
thank you for your time and support in filling out this survey.

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