

NAVAL POSTGRADUATE SCHOOL

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THESIS

**THE RELIABILITY CHALLENGE:
COMMON PITFALLS, AND STRATEGIES FOR
MAXIMIZING INHERENT RELIABILITY
PERFORMANCE OF WEAPON SYSTEMS**

by

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December 2001

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RELIABILITY PERFORMANCE OF WEAPON SYSTEMS**

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Submitted in partial fulfillment of the
requirements for the degree of

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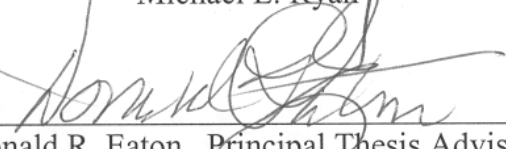
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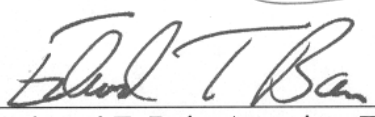
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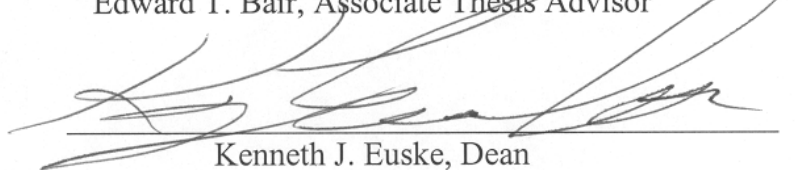
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ABSTRACT

Demonstration of required reliability performance levels prior to system fielding has remained a challenge for the Army, and in recent years, the success rate of systems achieving their stated reliability performance in operational tests has declined. Realization of required reliability performance necessitates effective management strategies and techniques in order to reduce risks. Furthermore, managing reliability performance does not stop upon fielding and must be continually monitored and assessed for potential improvements and efficiencies in support of meeting Army readiness objectives.

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I. INTRODUCTION

A. BACKGROUND DISCUSSION

The Army Vision calls for a strategically responsive force with the ability to put a combat capable brigade anywhere in the world in 96 hours; a division in 120 hours; and five divisions in 30 days. This equates to a need for high readiness levels for rapid deployment, and a significantly reduced logistics footprint in the battlespace without jeopardizing combat capability. One enabler to achieving this is highly reliable systems. Highly reliable systems are force effectiveness multipliers, as the resulting benefits contribute towards reduced maintenance times, increased system availability, reduced training and manpower, less spare parts, and a net reduction in total ownership costs (TOC) that equates to the freeing up of scarce funds needed for Army modernization..

Demonstration of required reliability performance levels prior to system fielding has remained a challenge for the Army. According to the Army Test and Evaluation Command (ATEC), the success rate for systems either in development or operational testing over a 5-year period from 1996 to 2000 was only 36%, with system operational test success rate with respect to reliability was only 20%. [Ref. 1] Failure to achieve reliability performance requirements at this late stage of development can have devastating impacts on a program, to include fielding delays, or fielding of a less than optimal solution, with resultant increased costs to address and retest problems later.

The United States General Accounting Office (GAO) has addressed the issue of “late cycle churn”, the scramble to fix significant problems discovered late in a weapon systems development, and concluded that among other things, early testing to validate product knowledge is key. [Ref. 2] Likewise, there are many early, upfront opportunities in a program for addressing reliability. First, requirements generation and the systems engineering process are areas where early influence can make a difference. Secondly, program planning and organizational management can emphasize a rigorous reliability process throughout the development phase. Lastly, incremental testing to ensure attainment of increasing levels of system maturity will ensure that systems operate in the field as intended.

B. OBJECTIVES AND PURPOSE OF THE RESEARCH

Achievement of required reliability performance necessitates effective management strategies and techniques to address reliability risks over the course of a weapon system's development and fielding. This research evaluates how weapon system reliability performance is managed in the acquisition process, and the challenges encountered by the Army in achieving operational requirements in support of readiness objectives. It evaluates all aspects of reliability management and ascertains where there are shortcomings, and provides recommendations for improvement. The objective is to determine how to best manage reliability, identify upfront cost-effective opportunities for improving reliability performance, and mitigate associated risks during design, manufacturing development, test, and post-production. Predictability in the field is the desired end state, which translates into increased operational availability; proficient use of personnel and skills; realistic levels of spares and repair parts; and ultimately an efficient and effective logistics tail that enables the Army to rapidly deploy and sustain forces in any theater of operation.

C. RESEARCH QUESTIONS

The Primary research question is:

What essential steps can a Program Manager take to better manage weapon system reliability requirements over a program's life cycle, and how can reliability performance be maintained and/or improved once the system is fielded?

Subsidiary research questions are:

1. What are the predominant underlying factors that contribute to reliability performance in Army systems, and how can a Program Manager (PM) mitigate risk in these areas?
2. What are the current policies and regulations that govern reliability of weapon systems, and do they provide PMs with adequate guidance?

3. How does the Army address reliability performance of a weapon system in the requirements generation process, and to what extent can a PM influence this process?
4. How is reliability addressed in the system engineering process, and what technology, tools and techniques are available to ensure reliability of a system is "designed in" upfront?
5. How has acquisition reform and the shift to performance based contracting impacted the reliability of weapon systems?
6. To what extent does commercial industry differ in their approach towards product reliability, and can the Army leverage these best practices to improve performance in military systems?
7. How is system reliability addressed as part of the test program, and what program strategies can a PM employ to ensure that a system will successfully pass reliability testing with a high level of confidence?
8. How do PMs plan to manage and track reliability, and what metrics are useful for measuring reliability performance during various stages of system development?
9. How does a PM contract and incentivize for reliability with industry, and are there potential areas for improvement?
10. Once a system is fielded, how does a program office ensure reliability performance is maintained, and what further can be done to improve reliability performance of fielded systems?

D. SCOPE, LIMITATIONS AND ASSUMPTIONS

The scope of this research includes an evaluation of reliability management considerations from several aspects: 1) the requirements generation process and the interface with the User, 2) the Program Manager's (PM) perspective during system development and test, 3) approaches to reliability growth, and 4) commercial best practices with Industry. Current policy and guidance regarding materiel developer

management responsibilities with respect to reliability is reviewed for adequacy. Ongoing Army reliability improvement initiatives are also reviewed, to include an assessment of current technology, tools, and techniques available to PMs to manage system reliability maturation prior to transition to production.

This research is limited to an analysis of systems in various stages of the acquisition process that are managed within the Program Executive Office for Intelligence, Electronic Warfare & Sensor (PEO IEW&S). The analysis addresses management approaches of PEO IEW&S and its PMs with respect to reliability performance, common issues encountered by PMs and reasons why they occur, risk mitigation techniques, contracting approaches for reliability, and lessons learned. The analysis is limited to an assessment of reliability management and process issues, and does not specifically address commodity or technology driven reliability problems. Although this research is limited to reliability of sensors and electronics systems, it is assumed that the management challenges, issues, and potential solutions can apply to other types of weapon systems as well.

E. METHODOLOGY

The methodology used in this thesis research consists of 2 steps. The first step is to provide an overview of the contemporary reliability environment within the Army. Current policies and regulations that govern reliability of weapon systems are reviewed for adequacy with respect to guidance given to materiel developers. The requirements generation process and the systems engineering process are evaluated with respect to how reliability requirements are dealt with, and to what extent these early processes influence reliability success in a program. Acquisition reform, current Army reliability initiatives, commercial best practices, and contracting methods for reliability are evaluated by literature reviews and interviews with acquisition professionals. Program management techniques and metrics that measure reliability performance are also assessed in the same manner. A comprehensive literature review on the subject of reliability includes material and sources that include, but are not limited to:

1. DoD and Army publications
2. Published academic research papers
3. References, publications, and electronic media available at the Naval Postgraduate School (NPS)
4. World Wide Web sources (DoD, commercial, academic)
5. Interviews with School of Business and Public Policy faculty at NPS

The second step entails an analysis of systems managed within the Program Executive Office for Intelligence, Electronic Warfare & Sensor (PEO IEW&S). This analysis includes systems in various stages of the acquisition process: Concept Technology Demonstration (CTD), System Development and Demonstration (SDD), Production & Deployment (P&D), and Operations & Support (O&S). Data gathering and analysis was conducted by personal interviews, telephone calls, emails, and through a reliability performance survey. Evaluation of systems in various stages of development and technical maturity provides a good cross-section of how reliability is managed across a program's lifecycle. The analysis synthesizes various PM's perspectives on managing reliability requirements; the coordination that is involved in dealing with the User, test community, and Industry partners; what are the common issues; reasons why they occur; and how these risks can be reduced.

F. ORGANIZATION OF THE STUDY

This thesis consists of five chapters. The first chapter is an introduction and provides the structure and lays the groundwork for the research methodology. Chapter II will define reliability and will provide background information as well as a discussion on policy and regulations regarding reliability. The status of reliability within the Army today will be addressed as well as current trends and issues concerning this important topic.

Chapter III will provide background information on the systems managed by PEO IEW&S that are a part of this study, present the results of a reliability performance survey, and discuss program's experiences with managing reliability. This will include relevant experiences regarding reliability in terms of developing valid requirements,

contracting, development and test, challenges during operational test, the impact of acquisition reform, best practices, and finally, maintaining reliability in the field.

Chapter IV then analyzes and compiles the key issues and challenges associated with reliability, and discusses risk mitigation techniques and strategies for maximizing inherent reliability. Barriers associated with achieving stated reliability performance are also be addressed.

The final chapter makes conclusions and recommendations, and provides answers to the primary and subsidiary research questions. Additionally, the final chapter will suggest areas that require further research.

G. BENEFITS OF RESEARCH

This thesis is conducted on behalf of PEO IEW&S and its PMs, and could have broader Army benefits as well. The primary benefit of this study will be identification of policy and program management issues with respect to weapon system reliability, and recommendations for areas of potential improvement. It is intended to directly benefit any PM that is, or will be managing complex programs, by identifying potential pitfalls, providing lessons learned, and suggesting methods for managing and reducing the inherent risks associated with achieving stated reliability performance requirements of weapon systems. Achieving stated weapon system reliability requirements is a challenge, one that PEO IEW&S is constantly dealing with, especially with the complex, software-intensive systems that it fields. Many organizations and working groups are aggressively looking into methods to improve reliability, and with this study I intend to pull these pieces together to present the “bigger picture”. By evaluating the common issues that many PMs deal with, identifying their underlying root causes, and suggesting potential methods for mitigating these risks, it is my hope that this study will benefit current and future PMs, and ultimately the soldier.

II. RELIABILITY OVERVIEW AND BACKGROUND

A. INTRODUCTION

This chapter provides the reader with background information on reliability management as it pertains to weapon systems in general, and within the framework of the defense acquisition process. To begin this chapter, a number of reliability definitions and terms are addressed to provide a common frame of reference and establishes a general basis of understanding for subsequent discussions. Following that, six main areas are discussed. First, an examination of current DoD and Army policies, procedures, and guidance regarding reliability is provided to establish the basis within which organizations must operate to manage reliability within a program. Second, how reliability fits within the framework of the acquisition process is reviewed. Third, methods for managing reliability performance are addressed. Fourth, a comparison of commercial vs. military reliability differences is provided. Fifth, the “cost” of reliability is discussed. And finally, this chapter concludes with an examination of the status of reliability trends and issues within the Army today.

B. RELIABILITY DEFINED

It is not surprising that the terminology used for reliability is nonstandard, and tends to vary depending on the Service and/or system. Metrics employed in most engineering disciplines are carefully defined and controlled in terms of method of measurement, and there is generally a universal agreement on their definitions. On the other hand, reliability, maintainability, and supportability fields use metrics that are somewhat specialized rather than naturally defined. The 361-page book entitled, *Reliability, Availability, and Maintainability (RAM) Dictionary*, published by the American Society for Quality Control and considered the "Webster's Dictionary" of RAM, illustrates this point. Moreover, there are in excess of 2000 reliability-related terms defined in documents reviewed thus far, many of which have similar meaning but different definitions. [Ref 3] It is important to note this because a clear understanding by all parties is required on what the reliability terms signify in requirements documents and in contract specifications.

1. Select DoD Reliability Definitions and Measures

Although now cancelled, MIL-STD-721C “Definition of Terms for Reliability and Maintainability” previously provided DoD and defense contractors with common definitions and terms. The Defense Systems Management College (DSMC) now provides a comprehensive set of definitions regarding reliability, availability and maintainability. The following definitions are found in the DSMC Acquisition Logistics Guide: [Ref. 4]

Reliability. Reliability is the probability that an item will perform its intended function for a specified interval under stated conditions. In simple laymen terms, it is how long the system can work. Mean Time Between Failure (MTBF) is commonly used to define the total functioning life of a population of an item during a specific measurement interval divided by the failures during that interval.

Mission Reliability. Mission reliability is the probability that a system will perform mission-essential functions for a period of time under the conditions stated in the mission profile. In other words, it’s the probability that no failure severe enough to prevent satisfactory mission accomplishment will occur during the mission.

Logistics Reliability. Logistics reliability is the probability that no corrective maintenance or unscheduled supply demand will occur following the completion of a specific mission profile. Logistic reliability basically tracks the rate at which failures cause logistics demands to be placed on the system, regardless of its effect on the mission.

Maintainability. Maintainability is the probability that if prescribed procedures and resources are used, an item will be retained in, or restored to, a specific condition within a given period. It is the inherent characteristic of a finished design that determines the amount of maintenance required to retain or restore the system into a specified condition. Corrective maintenance can be measured by Mean Time to Repair (MTTR); or, stated in more simple terms, how quickly and easily the system can be fixed. Also, Mean Maintenance Time (MMT) or Mean Time Between Maintenance (MTBM) not only includes corrective (unscheduled) maintenance but also accounts for preventive (scheduled) maintenance.

Availability. Availability is based on the question, "Is the equipment available in a working condition when it is needed?" Availability is defined as the probability that an item is in an operable and committable state at the start of a mission when the mission is called for at a random point in time. The User is most concerned about this parameter as it directly reflects the readiness of the system. There are a number of types of definitions of availability, all based on a standard mathematical relationship, with differing definitions of the terms "Up Time;" "Down Time;" and "Total Time". Operational Availability (Ao), covers all time segments the equipment is intended to be operational, and is the most desirable form of availability to be used in helping assess a system's potential under fielded conditions.

Inherent Reliability. Inherent reliability is the potential reliability of a system, and assumes an ideal operating and support environment.

A few nuances are worth mentioning here. It should be noted that redundancy, a practiced reliability design technique, while usually an improvement to mission reliability, almost always has an adverse impact on logistic reliability. Table 1. contrasts the differences between the two. Another interesting point is that MTBM is considered a more logistically significant measure than MTBF as it captures both scheduled and unscheduled maintenance actions.

LOGISTICS RELIABILITY	MISSION RELIABILITY
• Measure of system's ability to operate without logistics support • Recognizes effects of all occurrences that demand support without regard to effect on mission. • Degraded by redundancy • Usually equal to or lower than mission reliability	• Measure of system's ability to complete mission • Considers only failures that cause mission abort. • Improved by redundancy • Usually higher than logistics reliability

Reliability Engineers Toolkit: Rome Laboratory

Table 1. Characteristics of Reliability Performance

2. Army Reliability Definitions

The following provide the Army perspective on reliability definitions from a logistics, test and overall mission perspective.

a. AR 700-127, Integrated Logistics Support

Reliability is a fundamental characteristic of a system expressed as the probability that an item will perform its intended functions for a specified time under stated conditions. [Ref. 5]

b. DA Pamphlet 73-5; Operational Test and Evaluation Guidelines

Reliability deals with the assurance that a system will not encounter an unacceptable number of failures during operation (frequency of failure), and is generally expressed as an operational measure in terms of "Mean Time between Operational Mission Failure." [Ref. 6]

c. RAND Study for the Army on Mission Reliability for Future Forces

Reliability is the probability that a piece of equipment will successfully perform its intended critical functions for a given duration measured in time or activity under specified conditions. [Ref. 7]

3. Commercial Definitions for Reliability

The IEEE Reliability Society's Standards Committee is working to develop a commercial standard to replace MIL-STD-785 "Reliability Program for Systems and Equipment Development and Production." In reviewing other commercial reliability standards and in researching commercial websites on the subject, it was found that there is virtually no distinction between how the DoD and private industry define reliability.

C. RELIABILITY POLICY, PROCEDURES AND GUIDANCE

Truly reliable systems have far-reaching impacts that go beyond the system itself. A reliable system will result in increased operational availability while requiring fewer spares, less personnel with specialized skills, and an overall reduction in the combat logistical footprint. Policies and regulations have been established to emphasize the importance of reliability and to ensure that we are striving towards this end.

1. DoD 5000.2-R, *Mandatory Procedures for Major Defense Acquisition Programs*

DoD 5000.2-R states that as part of the acquisition strategy for a given program, the PM shall develop and document a support strategy for life-cycle sustainment and continuous improvement of product affordability, *reliability*, and supportability, while sustaining readiness. RAM activities described in DoD 5000.2-R are summarized below:

- The PM shall establish RAM activities early in the acquisition cycle.
- The PM shall develop RAM system requirements based on the Operational requirements Document (ORD) and Total Ownership Costs (TOC) considerations, and state them in quantifiable, operational terms that are measurable during development and operational test.
- 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. [Ref. 8]

2. AR 70-1, *Army Acquisition Policy*

AR-70-1 implements DoD 5000.2-R and governs research, development, and acquisition, and life cycle management of Army materiel to satisfy approved Army requirements. The regulation places responsibility squarely on the shoulders of the PM to implement an effective reliability and maintainability (R&M) program:

- The R&M program will be tailored in scope and content and be designed to ensure that the user operational reliability requirements will be met at confidence levels established by the user.

- The PM is to actively participate with the User to establish R&M and other system requirements. These efforts will justify the up-front investment in R&M design, engineering and test necessary to meet ORD requirements and if required, will justify the trade-off of R&M characteristics necessary to keep within established cost targets.
- PMs are encouraged to utilize reliability growth planning tools and curves to evaluate progress towards meeting established R&M parameters. Intermediate program milestone thresholds and objectives should be developed from these curves.
- PMs are to track fielded systems failure and repair histories starting at First Unit Equipped (FUE). This effort should focus on the identification of operating and support cost drivers that lead to improvements where they are cost effective. [Ref. 9]

3. DA Pamphlet 70-3, *Army Acquisition Procedures*

DA PAM 70-3 provides discretionary guidance on materiel acquisition management and does a fairly good job with respect to addressing procedural guidance on reliability and maintainability (R&M) requirements. It applies to all Army organizations that have responsibility for the development, acquisition, and support of Army materiel. The guidance covers aspects of R&M Requirements, R&M Management, R&M Engineering and Design, R&M Testing, and R&M and Assessment Integrated Process Team (IPT) procedures. [Ref. 10]

D. RELIABILITY AND THE ACQUISITION PROCESS

Managing reliability in a program starts by understanding the User's system readiness and performance needs as part of the requirements generation process. Reliability performance should be continually assessed as part of an iterative process during development, test, and production, and on through fielding and sustainment. Reliability management requires constant attention and a reasonable approach, and there must be a balance. The life cycle costs of a weapon system can be exceedingly high if the reliability of a system is either excessive or inadequate.

1. Requirements Generation Process

The Combat Developer (CBTDEV) develops the Operational Requirements Document (ORD) and hence is ultimately responsible for defining the requirements relative to the reliability of the system. Typically this is defined in terms of operational availability and mission duration needs. Reliability requirements development, however, is not done in a vacuum. Developing quantitative operational reliability requirements, like all other ORD requirements, is a collaborative process between the CBTDEV and the Materiel Developer (MATDEV) using Integrated Product Teams/Integrated Concept Teams (IPTs/ICTs). This process provides a balanced solution between the best estimate of what is required to meet the user's effectiveness, suitability, and survivability needs, and that which is actually affordable and technically achievable within program funding, risk, and time constraints.

ORD reliability requirements are developed in accordance with AR 71-9. Three key elements combine to define overall reliability performance requirements. A change to any of these elements is a change to the basic requirement and requires appropriate coordination and approval.

1) Reliability parameters (such as Ao) and their numerical values. The analysis and rationale supporting the development of these parameters is documented by the CBTDEV.

2) Operational Mode Summary/Mission Profiles (OMS/MP). The OMS/MP is a supporting document that describes the mix of wartime and peacetime missions in which the system is required to perform, and the conditions (climate, terrain, battlefield environment, etc.) under which the missions are to be performed.

3) Failure Definition and Scoring Criteria (FDSC). The FDSC is a living document that matures as the program and system configuration evolve. It defines the required functionality of the system and what constitutes a reliability failure. The FDSC also establishes a framework for classifying and charging test incidents. [Ref. 11]

2. Systems Engineering Process

Given the trend towards development of increasingly complex weapon systems, reliability cannot be left as a matter of chance; it has to be consciously and proactively built into a system through good design and manufacturing practices. The starting point is the systems engineering process beginning with requirements definition and analyses, and the conduct of cost/benefit trade-off analyses to determine alternative requirements, allocations, and design solutions.

a. Design Tools and Techniques

Emphasis must be placed early on in the use of proper design tools and activities to “build in” reliability up front, rather than the rely on extensive “back end” testing and validation. Numerous reliability tools, methodologies and analysis techniques can be employed during the systems engineering process to ensure reliability requirements are realized. Effective application of these techniques can: reduce the need for reliability testing by achieving higher design reliability; reduce the need for costly fixes and upgrades; reduce system operations and support costs; and allow for more effective maintenance actions when failures do occur. The listing provided bellow is intended to give the reader a general understanding of some of these tools and techniques. The listing is not meant to be exhaustive or comprehensive in description.

- Physics of Failure (PoF). PoF is a proactive design technique used for designing reliability into a system by identifying and understanding the physical processes and mechanisms of failure. The purpose of using PoF tools is to design out failures prior to test and fielding. Electronic applications can be conducted at the board and device level employing vibration, thermal, and fatigue analysis tools. Mechanical component applications include solid modeling, dynamics simulation, and finite element analysis tools used in support of determining component fatigue failure mechanisms.
- Critical Items List/Analysis. Critical items are those requiring special attention due to complexity, application of state-of-the-art technology, high cost, single source, or single failure point components. Special controls are required for these items to reduce their inherent risk.

- Identification of Potential Reliability Problems. Known reliability problems (hardware/software, or procedural), their impacts, and proposed solutions or plans for resolution are identified in the design process.
- Software Reliability Assessment. A software assessment of the contractor identifies the metrics that will be used to measure the “goodness” of the product software reliability development process.
- Redundancy. Redundancy offers continued system operation given failure of one of the critical components/subsystems. Trade-offs to consider using this design technique are cost, increased maintenance, and size weight and power (SWAP) increases.
- Variability Production Processes & Quality Assurance. This includes processes and activities that will control defects and reduce variability resulting from manufacturing and production. Examples include statistical process control (SPC), six sigma, Taguchi methods, and ISO 9000.
- Parts Control Program. Parts control helps maintain/increase inherent system reliability through the use of preferred standard parts to minimize variation. It also can be utilized to take advantage of new more reliable technologies.
- Allocation and Prediction. Reliability allocation is performed early on in the program and allows for trade-off studies to be performed in order to achieve the optimal combination of subsystem reliability in which meet overall system requirements. The normal starting point is use of historical baseline data with adjustments based on type of technology and usage rates applied.
- FMECA, FRACAS, and FTA. The Failure Modes Effect & Criticality Analysis (FMECA) is a tool that is used to identify potential failure modes and their impact on the system. A Failure Reporting and Corrective Action System (FRACAS) is the process by which failures of an item are tracked; analysis conducted to determine root cause; and corrective actions

identified and implemented to reduce failure occurrence. Fault Tree Analysis (FTA) is a top down model that graphically depicts all known events or combinations of events that can occur leading to a specific undesirable event. [Ref. 12]

b. Disciplines Involved in Reliability Processes

A number of engineering, management, and logistic support disciplines come together and play a vital role in meeting a system's reliability objectives. The types of expertise and timing required for different tasks vary and depend upon many factors, e.g., type and complexity of design, mission profile, operational and support resources and constraints, etc. Table 2 summarizes the types of expertise that are typically involved in the reliability design of a system. [Ref. 13]

	System Engineering	Configuration Management	Quality Assurance	Component Engineering	Manufacturing	Processes Engineering	Designer	Logisticians	Thermal, Structural, Materials	Test Engineering	Safety
Critical Processes											
Requirements Identification and Analysis											
System	X	X						X			
Subsystem/Configuration Items	X	X			X		X	X	X	X	X
Design											
Allocation	X	X					X	X			
Prediction	X		X				X	X	X		
Failure Analyses	X		X		X	X	X	X	X		X
Parameter Design Analysis	X		X	X		X					
Fault Tree Analyses	X		X	X		X	X	X		X	X
Design Reviews	X	X	X	X	X	X	X	X	X	X	X
Component Derating	X		X	X			X		X		
Process Variability	X		X	X	X	X	X			X	
Risk Assessments	X	X	X	X	X	X	X	X	X	X	X
Verification											
Test	X		X	X	X	X	X	X		X	X
Inspection	X		X	X	X	X	X	X			X
Field Data	X		X		X			X		X	X

Source: CPAT - Reliability Engineering, Air Force

Table 2. Common Disciplines Involved in Reliability

3. Testing and Evaluation

Reliability testing serves a twofold purpose: 1) to mature the system, i.e. to reveal design and process deficiencies through reliability growth and pre-qualification testing so that corrective action may occur when it is least costly to fix; and 2) to determine compliance with the requirement through formal qualification or demonstration testing. Testing should compliment design work, not replace it and emphasis should be placed upon designing out failures well prior to formal reliability test events. Accelerated test strategies such as Highly Accelerated Life Testing (HALT) quickly aid in the identification of weak parts and provides for quicker maturation. Test, Analyze, Fix, Test (TAFT) strategies can also be effective as long as sufficient resources exist (test assets, schedule time, and dollars) to support overall program acquisition timelines. Reliability qualification or demonstrations tests and successful achievement of operational reliability requirements in the form of an operational test are required prior to production to demonstrate contractual compliance and operational suitability for fielding.

Various contractor and government tests (both technical and operational) can be used to demonstrate compliance to contractual and operational reliability requirements. A partial listing provided below is provided. The listing is not meant to be exhaustive or comprehensive in description.

- Environmental Testing. These types of tests are contractual qualification tests of the system's ability to operate during and after exposure to environmental extremes and are typically conducted in environmental lab chambers.
- Accelerated Testing. Accelerated testing techniques precipitate failure modes quickly by increasing the component or system's stresses. To be cost effective, accelerated testing should be performed early in the system design.
- Reliability Development/Growth Testing (RD/GT). RD/GT is a test-analyze-fix-test (TAFT) method used to surface failure modes on prototypes and production systems/subsystems so that fixes or corrective

actions may be applied to mature reliability. Testing is conducted using the normal OMS/MP expected to be seen by the system.

- Reliability Qualification/Demonstration Testing. In RQT or RDT, a “fixed configuration” type test, i.e. no fixes allowed as in RD/GT, is conducted to specifically demonstrate compliance with a reliability requirements. This type of testing can be conducted prior to a production decision, or post-production on systems from the first production lot to ensure the system has retained its inherent reliability in production.
- Government Developmental Testing. These tests may take on forms of field environmental testing or tests to ensure achievement of technical performance, safety, supportability, durability and RAM. These tests may augment contractor system level integrated testing as well as operational testing.
- Operational Testing. The decisive test for reliability entails testing in an operational environment in accordance with the system’s OMS/MP, with trained troops, using approved Army doctrine and tactics, techniques, and procedures.
- Early User Test(EUT)/Limited User Test(LUT). EUT is an operationally oriented test conducted early in the acquisition process to gather data in support of a selection of a single system concept from multiple ones considered for continued development. This can provide early insight on the reliability of a chosen system. LUT is an operational test used to verify fixes or to satisfy effectiveness, suitability and survivability issues from a prior operational test. Estimates of operational reliability may be obtained to support a low rate production decision.
- Initial Operational Test. IOT is the pinnacle test event for the system and for reliability. It is here that ORD reliability requirements must be met in order to support a full rate production decision. Data from other test events may be aggregated with IOT reliability data, given compliance

with three criteria: 1) tests conducted under similar environments; 2) same production configuration, and 3) homogenous failure rates between tests.

- Follow-On Test (FOT). Any deficiencies found during IOT, including those related to reliability, must be corrected. FOT serves the purpose of demonstrating those fixes so that the system can be declared effective, suitable, and survivable. [Ref. 14]

4. Maintaining Reliability of Fielded Systems

A PM's responsibility is not over once a system is fielded. As mentioned earlier in this chapter, per AR 70-1, PMs are to track fielded systems failure and repair histories starting at First Unit Equipped (FUE). There is a good reason for this. Regardless of prior test results, estimates, or contractor predictions concerning the reliability of a system, high readiness rates must be upheld, and to do this a PM must ensure that *proven* reliability measures of a system are maintained. Among quality metrics, reliability is one of the most difficult to monitor and control. Although reliability of a system is tested throughout the acquisition process, reliability can be truly and accurately assessed only after a system has been in the field for some time. This implies collection of reliability field data. In addition, a PM's data collection efforts should focus on the identification of operating and support cost drivers with respect to reliability (or other aspects of the system for that matter) that can be improved upon via engineering changes and product improvements, as long as they are deemed cost effective.

Field data collection can provide information on warranty compliance as well as unresolved reliability issues from earlier operational testing. Of equal importance is the fact that these data will also serve as a historical baseline in support of the reliability requirements generation process for future systems. The Army measures reliability in the field by using specific, reportable, criteria to determine availability measures such as operational availability, or A_O and fully mission capable (FMC) rates. Systems are fully mission capable when they can perform all of their combat missions without endangering the lives of crew or operators. The terms ready, available, and full mission capable are often used to refer to the same status; equipment is on hand and able to perform its combat missions.

E. MANAGING RELIABILITY PERFORMANCE

Part of the PM program office's responsibilities entail performing timely and continuous assessments of progress towards achieving reliability performance requirements. This is accomplished with the use of appropriate phased testing to help measure and project reliability. Problem and failure reporting, tracking, analysis, and corrective action processes are utilized throughout the lifecycle of a program, with sufficient attention and resources allocated to this area. To help manage reliability activities throughout the development life cycle, the U.S. Army Materiel Systems Analysis Activity (AMSAA) has developed reliability growth methodologies for all phases of the process, from planning to tracking to projection. AMSAA's *Reliability Growth Handbook* provides sound methodology for reliability growth concepts and is considered a good source for reliability best practices. [Ref. 15]

It is also important to motivate the contractor to maximize the inherent reliability of a system during development, so that costly fixes are not required later on. Contracts should be constructed that provide incentives to the contractor to proactively identify and fix reliability problems. There should be close coordination between the government program office and the contractor to ensure a balanced approach is achieved between system reliability and overall program requirements and objectives.

1. Planning, Tracking, and Assessing Reliability Growth

Reliability growth is an integral piece to achieving highly reliable systems and should be seriously considered for any significant development program, especially those that incorporate complex state of the art technologies. Reliability growth is the improvement in a reliability parameter over a period of time due to changes in product design or the manufacturing process. It occurs by surfacing failure modes and implementing effective corrective actions. The following benefits can be realized by the utilization of reliability growth management:

- Finding Unforeseen Deficiencies
- “Designing in” Improvement through Surfaced Problems
- Reducing the Risk of Final Demonstration
- Increasing the Probability of Meeting Objectives [Ref. 16]

According to AMSAA, reliability growth management consists of planning, evaluating and controlling the growth process.

a. Reliability Planning

Reliability growth planning integrates program schedules, required levels of testing, the resources available, and addresses the realism of the test program in achieving the requirements. A reliability growth program plan curve is constructed that quantifies interim reliability goals throughout the program.

b. Reliability Growth Assessment

It is essential that periodic assessments of reliability are made during the test program and compared to the planned reliability growth values so that emphasis can be placed where warranted.

c. Controlling Reliability Growth

Done properly, reliability growth allows for correction of system deficiencies while there is still time to affect the system design. The process can be controlled by making appropriate decisions regarding timing of fixes with respect to the program schedule milestones.

2. Contracting for Reliability

Reliability objectives are translated into quantifiable and verifiable contractual terms, and should also be traceable to operational requirements. Prior to the advent of military specifications and standards reform in 1994, the work requirements for reliability engineering were usually described in a Statement of Work (SOW) task that required compliance with MIL-STD 785 *“Reliability Program for Systems and Equipment Development and Production.”* In February 1996, Mr. Gil Decker, the Army Acquisition Executive at the time, issued policy on incorporating a performance-based approach to Reliability in Requests for Proposals (RFPs). A key change was that no “how to” reliability standardization documents were to be used. The policy stated that:

“Reliability requirements should be included in RFPs by specifying: (1) quantified reliability requirements and allowable uncertainties, (2) failure definitions and thresholds, (3) life-cycle usage conditions.” [Ref. 17]

Mr. Decker's policy was institutionalized in the update to AR 70-1 in Jan 1998. AR 70-1 clarified several points of the AAE memo. "Allowable uncertainties" pertain to statistical risks; "failure definitions and thresholds" are defined in Failure Definition and Scoring Criteria (FDSC); and "life-cycle usage conditions" refer to the OMS/MP of the system.

Reliability parameters expressed by operational users and ones specified in contractual documents take many different forms. User requirements are generally expressed in a variety of forms that include combinations of mission and logistics reliability, or they may combine reliability with maintainability in the form of availability. Conversion from commonly used operational terms such as mean-time-between-maintenance (MTBM) and mean-time-between-critical-failure (MTBCF) must be made to enable translation to parameters which can be specified in contracts and verified in testing.

CONTRACTUAL RELIABILITY	OPERATIONAL RELIABILITY
• Used to define, measure and evaluate contractor's program • Derived from operational needs • Selected such that achieving them allows projected satisfaction of operational reliability • Expressed in inherent values • Accounts only for failure events subject to contractor control • Includes only design and manufacturing characteristics <u>Typical terms:</u> • MTBF (mean-time-between-failures) • Mission MTBF (sometimes also called MTBCF)	• Used to describe reliability performance when operated in planned environment • Not used for contract reliability requirements (requires translation) • Used to describe needed level of reliability performance • Include combined effects of item design, quality, installation environment, maintenance policy, repair, etc. <u>Typical terms:</u> • MTBM (meantime-between-maintenance) • MTBD (meantime-between-demand) • MTBR (meantime-between removal) • MTBCF (meantime-between- critical-failure)

Reliability Engineers Toolkit: Rome Laboratory

Table 3. Contractual vs. Operational Reliability

F. COMMERCIAL VS. MILITARY RELIABILITY DIFFERENCES

While there are numerous differences between the needs of the military customer and those of the commercial customer, the reliability needs of the military focus primarily on operational readiness (product performance on demand), operational longevity (long useful life vs. short life cycles), operational supportability (repair/replace vs. throwaway items), and operational robustness (satisfactory performance over environmental extremes). Table 4 provides an overview of the general differences between military and commercial customer needs. [Ref. 18]

MARKET/PRODUCT CHARACTERISTICS	MILITARY NEEDS	COMMERCIAL NEEDS
Useful Life	Typically 10-30 Years	Variable
Safety Factors	Low Risk to Personnel/Equipment	Application Dependent
Support Factors	Full Pipeline (100% Availability)	Application Dependent
Operational Factors	Performance on Demand is Critical	Performance on Demand is Desirable
Purchase Decision	“Best Value” Performance/Price Relationship	Consumer Expectations Met
Market Need for Product	Meet Adversarial Threat	Meet Market Expectations
Environmental Factor	Product Operation in Extreme Environments	Product Operation in Typical Environments

Reliability Toolkit: Commercial Practices Edition

Table 4. Characteristics of military vs. Commercial Needs

Although commercial products are less complex than defense weapon systems in general, the extreme difference in reliability requirements is quite startling; the Army requires levels of reliability in the *hundreds to thousands of hours*, whereas the commercial sector in some instances is asking for *millions of hours or years*. An example is a commercial telephone switching equipment that has less than two hours of downtime in *40 years*. Another example where similarly high reliability standards are in effect is at the National Aeronautics and Space Administration (NASA). Out of necessity, NASA has one of the most noted and perhaps best reliability programs in the

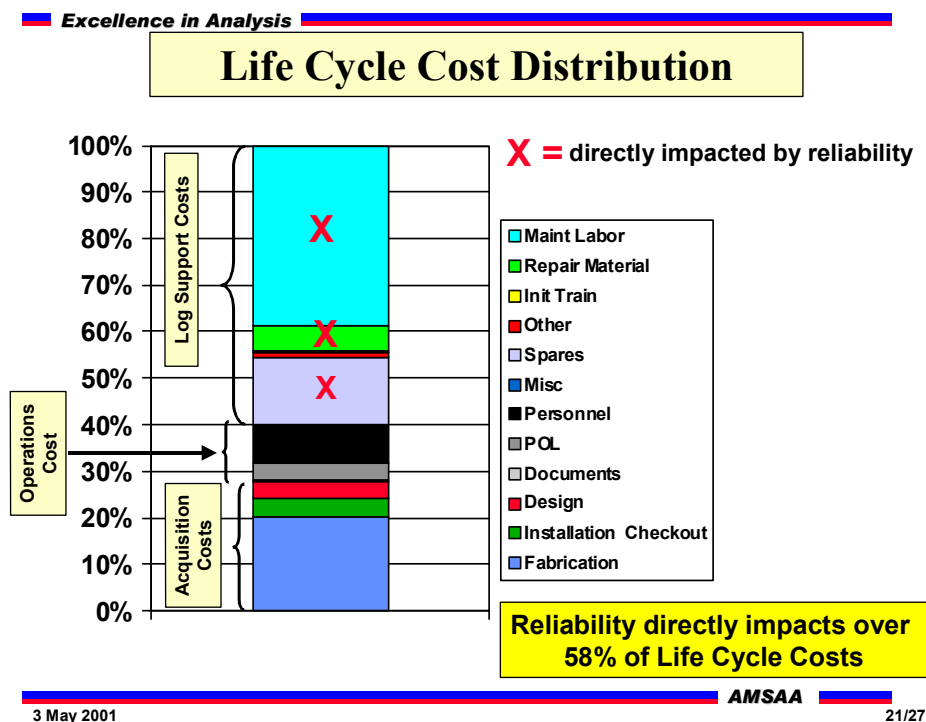
world. The space systems it builds simply must work, and so NASA demands that contractors develop reliable products that meet extremely stringent reliability guidelines. For example, for software requirements NASA uses the following definitions in terms of probability of failure $P(f)$ during a one hour mission:

- Low Reliability: $P(f)$ of greater than .001
- Moderate Reliability: $P(f)$ of between .001 and .0000001
- Ultra Reliable: $P(f)$ of less than .0000001

Of course, to get to levels of reliability that are in the “ultra” range does not come cheap. Highly reliable systems, like anything else, come with very high price tags.

G. THE COST OF RELIABILITY

The “cost” implications of reliability are far-reaching. Systems that are highly reliable are not only force effectiveness multipliers; the collateral reliability benefits of reduced maintenance times, increased system availability, reduced training and manpower, and less spare parts in the inventory equates to a decreased logistical burden that has considerable impacts on life cycle cost reductions.

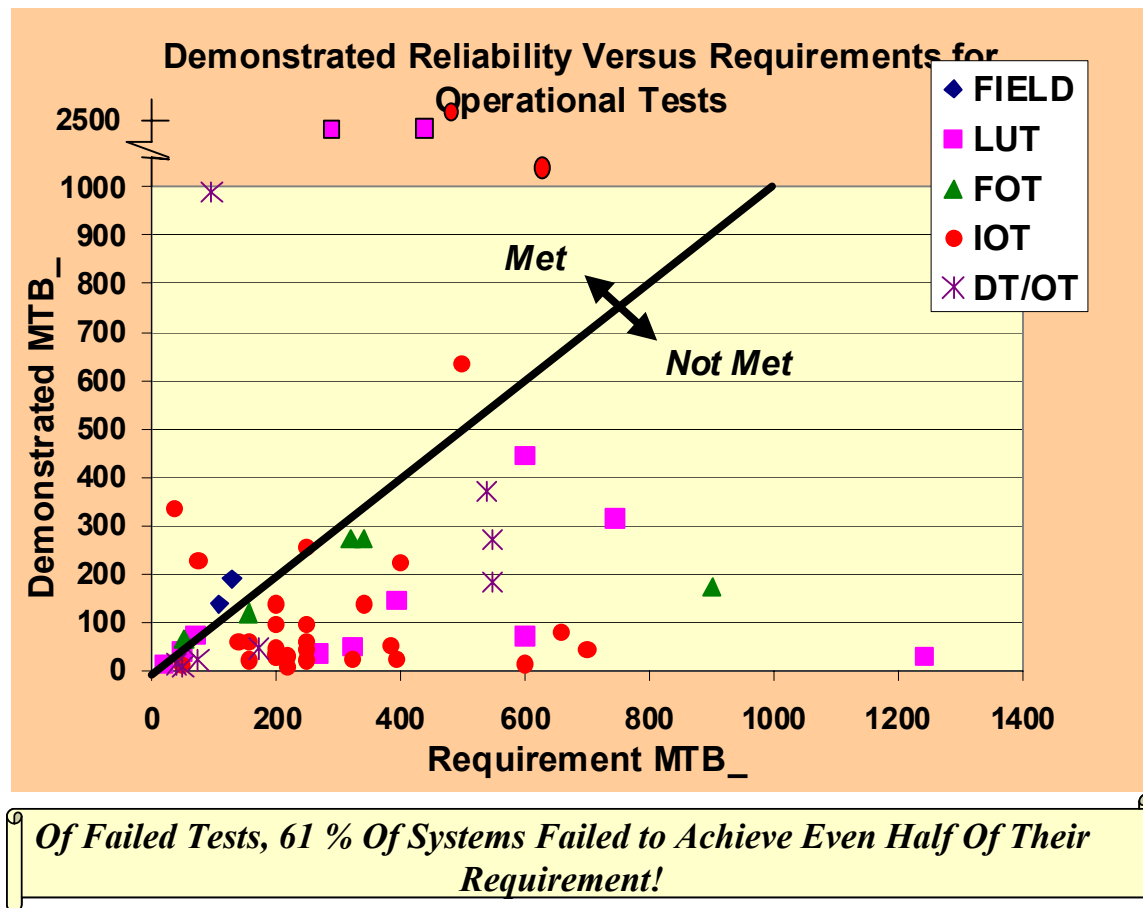


Source: DA ILS Symposium, Nov 97, J. Emahiser, ADUSD(L)

Figure 1. Impacts of Reliability on Life Cycle cost

H. CURRENT RELIABILITY TRENDS & STUDIES WITHIN THE ARMY

According to the Army Test and Evaluation Command (ATEC), the success rate for Army systems either in development or operational testing over a 5-year period from 1996 to 2000 was only 36%, and of those failed tests, 61% failed to even achieve half of their reliability requirement. System operational test (OT) success rate with respect to reliability was *only 20%*. [Ref. 19]



Source: AEC Presentation to PEO IEW&S, 20 Sep 2001

Figure 2. Army System Reliability Performance: 1996-2000

The chart above represents operational test events that were used as the basis for demonstration of reliability requirements. All acquisition category (ACAT) levels are represented here. The types of OT events included: Field exercises, IOTs, FOTs, LUTs, and combined DT/OT. Points above the diagonal achieved their reliability requirement during testing, while those below did not.

The issue of reliability performance, or lack thereof, has been an interest and concern at all levels of the Army lately. To its credit, the Army has chartered a Reliability and Maintainability (RAM) Panel to look at these concerns, identify problems, and explore solutions. A number of Army Reliability Workshops, sponsored by the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA(ALT)) and led by AMSAA, have been held over the past year to address shortfalls in the current process and enablers for improving the way the Army addresses reliability in the future. A number of sub-panels meet on a regular basis to focus on the following top-level reliability issues described below. The work of these panels is currently ongoing.

- Adequacy of reliability and Maintainability Requirements
- Contracting to Design in Reliability and Maintainability
- Reliability Validation
- Management Enforcement
- Adequacy of Reliability and Maintainability Workforce
- Field Systems Data

A number of recent studies have taken a closer look at reliability performance in weapon systems. One such study is the Army Science Board's FY2000 Summer Study, *Technical and Tactical Opportunities for Revolutionary Advances in Rapidly Deployable Joint Ground Forces in the 2015-2025 Era*. One of the focuses of this study is the Army's Future Combat System (FCS), a key cornerstone of the Objective Force and Army Transformation Vision. The Support & Sustainment sub-panel recommended making "ultra-reliability" a Key Performance parameter (KPP) for FCS, and also went on to recommend increased use and reliance on Physics of Failure (PoF) techniques and emphasized the incorporation of embedded diagnostics/prognostics. Of importance to note is that the panel recommended *mission* reliability be a KPP for FCS, vice system reliability. [Ref. 20]

I. CHAPTER SUMMARY

In this chapter, the researcher provided a broad descriptive background on reliability and how it is managed today within the defense acquisition process. Policies and procedures for incorporating reliability within the management framework of acquisition programs were discussed, as well as how reliability is addressed as part of an iterative process during development, test, and production, and on through fielding and sustainment. A picture of the contemporary reliability environment within the Army today was presented to set the stage for further review. It is evident based on recent downward trends in reliability performance test results that there needs to be better management of the reliability “risk” in programs. The Army has initiated several efforts to address the reliability problem and get systems “back on track”.

The next chapter presents results of a reliability performance survey that identifies reliability management techniques, issues, and methodologies employed by PM organizations within the Program Executive Office for Intelligence, Electronic Warfare & Sensor (PEO IEW&S). The survey included systems in various stages of the acquisition process and thus provides a good cross-section of how reliability can be managed across a program’s lifecycle.

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III. MANAGING WEAPON SYSTEM RELIABILITY PERFORMANCE

A. INTRODUCTION

This chapter identifies and discusses a variety of issues, common practices, concerns, and real-world experiences of Project and Product Managers as they relate to managing the reliability performance of Army weapon systems. Data is presented on programs ranging from ACAT I to ACAT III systems that are in various stages of development and production, from Concept and Technology Demonstration (CTD) through production and Operations & Support (O&S). The data was gathered through several sources; a reliability performance survey that was provided to each participating PM and program/project leader; interviews with program office personnel responsible for reliability testing; telephone calls; and emails. A copy of the survey that includes all of the questions and sub-questions is found in Appendix A. These questions were based on the literature review and the background research conducted on reliability as described in Chapter II. The questions were designed to draw out the practices employed by each PM organization (PMO) on managing reliability performance risks in their programs.

This chapter is organized around four main areas. First, the general methodology and process used in conducting the survey is provided along with some basic demographics on the programs involved. Then, a corporate overview of the participating organization is provided, along with a brief description of each PM and the programs involved in the reliability survey. Next, survey question responses, grouped by common themes, are presented and summarized, and where appropriate, specific program experiences are provided to further illustrate key points made. Finally, chapter conclusions are presented. *Note that the source for all tables found in this chapter is from the author, based on responses to the reliability performance survey.*

B. METHODOLOGY

Surveys were distributed to each PM organization via email with information regarding the objectives of the survey, and instructions for completing it. Survey respondents were typically not the PM him/herself, and were either the Program/Project

Leader (PL), or someone who had program responsibility in engineering, quality, testing, or had specific reliability expertise that was part of their primary job duties in the PMO.

1. Program Demographics

A total of 18 programs from five PM organizations were asked to participate in the survey. The participation response was 100%. The programs participating cover the full spectrum of ACAT levels and cross all acquisition phases. This should provide a fairly representative cross-section of experiences with respect to weapon system reliability performance management. Table 5 generically summarizes the program demographics by depicting programs by phase, broken out by ACAT level.

ACAT Level	MS A	MS B	MS C		O & S
			LRIP	FRP	
ACAT I	1	2	2	1	1
ACAT II				1	
ACAT III				4	
Non ACAT				4	

Table 5. ACAT and Acquisition Phase Demographics

2. Survey Areas of Interest

In all, there were 20 primary questions asked in the survey with some that had additional subparts. The surveys were developed to collect information on the eight main themes described below.

- Management Approach to Reliability
- Influencing Reliability Requirements
- Contracting and Incentivizing for Reliability
- “Designing-in” Reliability Upfront
- Development and Operational Test Experiences
- The Impact of Acquisition Streamlining and Downsizing
- Commercial Practices
- Maintaining and Improving Reliability in the Field

3. Data Presentation

The subsequent sections provide the data for this research and serve as the basis for analysis in Chapter IV. For the purposes of clarity, responses to the 20 survey questions are categorized into eight main themes: 1) Management Approach to Reliability; 2) Influencing Reliability Requirements; 3) Contracting and Incentivizing for Reliability; 4) “Designing-in” Reliability Upfront; 5) Development and Operational Test Experiences; 6) The Impact of Acquisition Streamlining and Downsizing; 7) Commercial Practices; and 8) Maintaining and Improving Reliability in the Field. Collectively, these eight themes correspond to issues addressed in the thesis research questions.

Each theme is generally laid out into four basic subparts. First, the purpose and objective of the survey question(s) within the main theme are addressed. Second, roll-up tables or paraphrased responses to survey questions are presented. Third, responses are summarized for the reader. Finally, a few illustrative examples of reliability program management experiences are provided as appropriate, to exemplify real-world challenges that PMs are often confronted with in dealing with reliability issues of weapon systems.

C. PROGRAM EXECUTIVE OFFICE INTELLIGENCE, ELECTRONIC WARFARE AND SENSORS

The Program Executive Office for Intelligence, Electronic Warfare and Sensors (PEO IEW&S) has responsibility for oversight and management of Army programs that provide critical and timely intelligence and sensor data at all echelons; to command and control systems at brigade level and above, to ground combat platforms, and down to the individual combat soldier. Its mission is *“To field and insert state-of-the-art, interoperable sensor capabilities and products which enable the land component commander to control time, space and environment, while enhancing survivability and lethality through continuous technology evolution and warfighter focus.”* PEO IEW&S is the warfighter’s expert on the exploitation of the visual and non-visual electromagnetic spectrum for intelligence, surveillance, reconnaissance and electronic warfare. Their core product line of sensor capabilities is based on signals intelligence, radar, laser, electro-optic, and infrared imaging technologies. Fielding relevant, reliable capabilities to the soldier is of paramount importance to PEO IEW&S, and is considered Job #1.

PEO IEW&S leads an organization consisting of four (06-level) Project Management Offices, one (06-level) Project Office, and two (05-level) direct-report Product Managers. Approximately two-thirds of all PEO IEW&S programs participated in the reliability survey, and many provided additional data to support this research. A brief description of the systems that participated is provided in the following sections.

1. Project Manager Common Ground Station (CGS)

PM CGS is responsible for systems that provide situational awareness and target information through command and control systems and ultimately to the end users. Two systems managed by PM CGS participated in the reliability survey.

a. Common Ground Station

The CGS is a tactical data processing and evaluation center that links multiple air and ground sensors to Tactical Operation Centers (TOCs) at Echelons Above Corps (EAC), Corp, Division, and Brigade. CGS integrates imagery and intelligence data into a single visual presentation of the battlefield, providing commanders with near real-time situational awareness. A good portion of CGS is designed with commercial off-the-shelf (COTS) components. CGS is currently in full rate production (FRP).

b. Joint Tactical Terminal/Common Integrated Broadcast Service Modules

The JTT/CIBS-M is a family of tactical terminals that provide critical intelligence and targeting information to battle managers, intelligence centers, air defenders, fire support elements and aviation nodes across all services. JTT/CIBS-M is currently in low rate initial production (LRIP).

2. Project Manager Night Vision/Reconnaissance, Surveillance and Target Acquisition (NV/RSTA)

PM NV/RSTA provides capabilities that enable commanders and their soldiers to conduct decisive operations at any time of the day or night. It is responsible for an extensive product line of sensor systems that employ a wide range of technologies to include electro-optical systems, image intensifiers, thermal infrared devices, radars, lasers, and multi-sensor suite systems. Nine systems managed by PM NV/RSTA participated in the reliability survey.

a. *Second Generation Forward-Looking Infrared*

The SGF system provides ground combat platforms such as the M1 Abrams, M2 Bradley, and the Long Range Advanced Scout Surveillance System with a common sensor for “own-the-night” operations. SGF is currently in FRP.

b. *Long Range Advanced Scout Surveillance System (LRAS3)*

The LRAS3 is mounted on a High Mobility Multipurpose Wheeled Vehicle (HMMWV) and provides real-time acquisition, target detection, recognition, and far target location information to the cavalry scout. LRAS3 is currently in FRP.

c. *Thermal Weapon Sight*

The TWS is a day/night thermal imaging device that and is mounted on individual and crew-served weapon systems. TWS comes in three configurations; light, medium, and heavy, and they are all in various stages of LRIP and FRP.

d. *Driver’s Vision Enhancer*

The DVE provides drivers of combat and tactical wheeled vehicles with a low-cost thermal imager that allows mobility in all weather, day or night, and in battlefield obscurants. DVE is currently in FRP.

e. *Lightweight Video Reconnaissance System*

The LVRS captures and transmits still frame images for use at higher echelons and is employed by surveillance and reconnaissance teams. LVRS, which consists primarily of COTS hardware and software, is currently in post-production operations and support (O&S) and is also undergoing several product improvements.

f. *Lightweight Laser Designator Rangefinder*

The LLDR is a tripod-mounted day/night target designator with a digital target location capability and is used by fire support teams. LLDR is currently in LRIP.

g. *Image Intensification Systems*

Individual soldiers use various types of Night Vision Goggles (NVGs) in combat, combat support, and combat service support operations. The family of NVGs includes the standard AN/PVS-7D NVGs; the Monocular Night Vision Device (MNVD); and the Aviators Night Vision System (ANVIS). The image intensification technology used in NVGs has matured over the past two decades, and has increased performance and reliability with each new generation. All NVG systems are in FRP.

h. Profiler Meteorological Measurement System

The Profiler MMS is the next generation meteorological system that provides weather prediction information to fire support systems. Profiler is currently in system design and development (SDD).

i. Synthetic Aperture Radar/Moving Target Indicator Payload

The SAR/MTI payload will be the first of a series of advanced sensor payloads to be developed for the Shadow Tactical Unmanned Aerial Vehicle (TUAV) system. The SAR/MTI system recently transitioned from its Advanced Technology Demonstrator (ATD) phase and is presently in the early stages of SDD.

3. Project Manager Signals Warfare (SW)

PM SW provides overall management of Army ground and airborne electronic warfare and signals intelligence collection systems. Three systems managed by PM SW participated in the reliability survey.

a. Aerial Common Sensor

The ACS is the Army's objective airborne Intelligence, Surveillance and Reconnaissance (ISR) system. ACS will eventually replace the legacy Guardrail Common Sensor and Aerial Reconnaissance Low systems and is in the early stages of Component Advanced Development (CAD).

b. Guardrail Common Sensor

The Guardrail Common Sensor is a Corps level airborne signals intelligence system that is currently fielded in several locations in the U.S., Europe, and Korea, and is in post-production O&S.

c. Prophet

The Prophet system is the Division and Armored Cavalry Regiment Commander's principal ground-based signals intelligence and electronic warfare system. Prophet Block I is currently in FRP.

4. Project Manager Tactical Unmanned Aerial Vehicle (TUAV)

PM TUAV is designated as the Army's centralized manager for tactical unmanned aerial vehicles. Two systems managed by PM TUAV participated in the reliability survey

a. Shadow Tactical Unmanned Aerial Vehicle

The Shadow system provides the maneuver brigade commander with near real-time RSTA, situational awareness, and battle damage assessment (BDA). Shadow is currently in LRIP.

b. Hunter Tactical Unmanned Aerial Vehicle

The Hunter system provides similar capabilities as the Shadow but at the Division level. Hunter provides the Army with a training base and contingency capability and is currently in post-production O&S.

5. Product Manager Combat Identification (CI)

PM CI programs address the need to minimize fratricide on the battlefield. Two systems managed by PM CI participated in the reliability survey.

a. Battlefield Combat Identification System

The BCIS provides tactical ground combat platforms with a question-and-answer combat identification system. BCIS is currently in LRIP.

b. Individual Combat Identification System

The ICIDS is a dismounted soldier point-of-engagement fratricide prevention system. ICIDS is currently in LRIP.

D. RELIABILITY MANAGEMENT WITHIN PEO IEW&S

1. General

PEO IEW&S is responsible for over 30 programs ranging from relatively simple Thermal Combat ID panels to large, complex systems such as Guardrail and the CGS. In the past year alone, during the period July 2000 to June 2001, PEO IEW&S and its PMs have fielded over 15,000 items. The ensuing sections contain responses from programs within PEO IEW&S to the reliability performance survey, augmented by some examples of specific program experiences on reliability management challenges. Before that data is presented, a brief examination of how PEO IEW&S maintains oversight in this area is warranted.

2. Reliability Performance Oversight

There are several methods in which PEO IEW&S maintains “corporate” oversight in the area of reliability performance of the weapon systems it manages.

a. *Acquisition Program Baselines (APBs)*

Each program has an APB that defines the cost, schedule, performance, and supportability measures that it must meet, with thresholds and objectives defined that serve as boundary parameters within which the PM operate. The APB serves as a “contract” of sorts between the PM and the Milestone Decision Authority (MDA), which in many cases is the PEO. Reliability related parameters such as MTBF, Ao, MTTR, and MTBM exist for each program either in the Performance or Supportability sections of the APB. The APB status of each program is reviewed once a quarter and at major reviews.

b. *Acquisition Decision Memorandums (ADMs)*

When a program reaches a major milestone or experiences a significant change in its program parameters, the outcome is documented in an ADM. These ADMs document decisions made by the MDA, and typically include additional directive statements that the PM must comply with. A review of all ADMs for existing programs revealed that many included statements and directives related to achieving or improving higher reliability levels for the programs. An ADM database tracking system has been established within PEO IEW&S that provides the status of all open actions described in program ADMs, to include those related to reliability. This database is periodically reviewed, with special attention given when a program is approaching its next milestone decision review. Several examples of PEO IEW&S ADMs are provided that place exit criteria, constraints, or follow-on actions related to reliability performance.

- “The PM will have the contractor identify the reliability baseline and their plan to integrate growth throughout the programs lifecycle. The PM shall include a contractual incentive strategy to facilitate the same.”
- “Complete RDGT with measurable results that demonstrate ORD threshold MTBOMF of 2,200 hours.”
- “...build sufficient quantities for system performance, reliability and operational testing.”
- “Demonstrate the capability to have R&M that supports mission accomplishments in an operational environment.”
- “The PM shall brief the PEO within 30 days of exercising the contract options to demonstrate how the PM will ensure reliability performance of at least 500 hours MTBF.” CONSTRAINT: “no additional work is to commence until the PM-Contractor addresses the process used by the contractor to demonstrate reliability required in the contract.”

c. Test and Evaluation Master Plans (TEMPs)

The TEMP for each program is reviewed to ensure that appropriate resources are available to support the test program for a given system. The TEMP usually addresses how, when, and where reliability performance will be tested.

d. Sustainment Cost Management Annex (SCMAs)

The Sustainment Cost Management Annex (SCMA) is a document that describes a PM's approach towards Total Ownership Cost (TOC) for a system. SCMAs are a living document, and are typically prepared as part of a program's acquisition strategy. The SCMA identifies a program's top ten O& S cost drivers, details plans and resources required to reduce these costs, and provides metrics to measure progress. Several programs within PEO IEW&S have specific strategies for reducing TOC through improvements in the reliability of their systems.

e. Program Reviews

The reliability performance progress and plans for improving inherent reliability of a system are addressed at every major review of a program. As a PM, when you show up at a review with the PEO, be prepared to answer the question "What are you doing and where are you at with achieving the stated reliability of your system?"

E. MANAGEMENT APPROACH TO RELIABILITY

Purpose: The first series of survey questions focused on how reliability performance and its associated risks are managed. These questions asked PMOs: 1) based on their actual experiences, what did they perceive to be the key factors that contribute towards reliability risk in a program, and how did they attempt to mitigate these risks; 2) how is reliability performance managed within a PMO in terms of roles and responsibilities, documentation, tracking progress, and reliability growth; and 3) the level of understanding of DoD and Army policy and guidance concerning reliability.

1. Key Factors Contributing to Reliability Performance

Objective: The first area of focus was intended to get right to the heart of the matter, that is, why do systems continue to struggle with reliability? Why do we often fail to meet required reliability goals? As part of an ongoing series of Army Reliability Workshops established by the Military Deputy ASA(ALT) to look at reliability concerns,

some common prevailing issues and concerns were identified by Army organizations regarding how reliability is addressed in the acquisition process. [Ref. 21] A “Top 10” list was developed and provided to all participants of the reliability performance survey to rank as they see fit, in order to gain better insights from those closest to the problem. Next, given these known or perceived risk areas, PMs were asked what kind of risk mitigation techniques do they employ to reduce these issues.

a. Top Ten Army Reliability Management Issues

The survey asked all participants to rank order what they felt were the “Top 10” reliability Army reliability issues, using the list developed by the Army RAM panel. Respondents were given the opportunity to nominate their own issues as well. Table 6 compiles all responses to provide an overall composite order of merit ranking.

Survey Responses:

"TOP 10" ARMY RELIABILITY ISSUES
Poor reliability growth planning (test too late)
Not aggressively "designing-in" reliability upfront
Insufficient reliability testing to verify requirements
Reliability is not a KPP
Unrealistic reliability requirements/rationale
Lack of qualified personnel in reliability management
Inadequate policies and procedures
Not designing sufficiently above requirement
Contractors not using best commercial practices
Not consistently improving reliability after fielding

Table 6. Top “10” Army Reliability Issues

Summary: The top three reliability problems as ranked by the respondents were: 1) Poor growth planning/testing too late; 2) Not aggressively “designing-in” reliability upfront; and 3) Insufficient reliability testing to verify requirements. These areas were clearly identified as especially problematic as at least half of all respondents choose these 3 problems as one of their top three issues. Interestingly though, each of the first seven ranked factors received at least one #1 vote.

b. Reliability Risk Mitigation Techniques

The next following answers were in response the survey question, “What risk mitigation techniques does your program employ that address system reliability performance?” Answers are paraphrased below.

Survey Responses:

- We leverage other test events. For example, we collect reliability data when soldiers are training on the system. This gives us an opportunity to better assess performance than just training data alone.
- Our contract has a hard requirement for Failure Analysis and Corrective Action and includes an essential Reliability Growth program.
- We do Environmental Stress Screening (ESS) and environmental testing to ring out early problems. RGDT is good for final core system certification.
- Because of extremely low reliability indicators observed during Engineering & Manufacturing Development (EMD) we have implemented intense oversight of the reliability process to include ESS, HALT, and RQT.
- Our program is in the early phases of Concept Exploration/Component Advanced Development. We use a Probability Consequences Screening model to identify risk management items. Its goal is to migrate high-risk/high-probability candidates to to a more manageable low-risk/low-probability level.
- The program convenes regular failure review boards to address reliability failures as well as corrective actions.
- Test early and often. Use HALT, RDGT, tear down audits, ESS.
- A reliability llocation model is used for for subsystems

Summary: There was slightly higher than a 50% response rate on this question, whereas most every other survey question received full attention. The primary methods and techniques for mitigating reliability performance risks include leveraging other testing to gain valuable reliability data, testing early and often, and use reliability growth to gain early knowledge and implement corrective action.

2. Managing Reliability in Acquisition Programs

Objective: The next series of answers were in response to the questions concerning how PMs manage reliability. The intent is to determine: a) how reliability

management is assigned in terms of roles and responsibilities within a PMO; b) if there is a process in place specifically for reliability management, and how is it formally documented; c) is there a reliability growth strategy in place; and d) what measures does management employ to continually assess reliability performance and progress.

a. Roles and Responsibilities

This question sought to determine how PM's delegated responsibility for reliability activities within a program. If the reliability activities of a program are conducted within the context of an Integrated Product Team (IPT), responders were asked if the IPT was formally chartered.

Survey Responses:

Responsible for Reliability Within PMO	Total	%	Chartered IPT?	
			Y	N
PM	1	6%		
Project Leader	1	6%		
Systems Engineering Team Lead	2	10%		
Logistics/Supportability Team Lead	3	16%		
Test Team Lead	1	6%		
Reliability IPT	9	50%	2	7
Prime Contractor	0	-		
No One Specifically	1	6%		

Table 7. Reliability Management Responsibility Within the PMO

Summary: Responses varied across the board on how PMs delegate management responsibility with respect to reliability performance. None left it entirely up to the contractor, and 50% of the programs have a Reliability IPT with representation from many of the disciplines listed in the table above. Of the nine Reliability IPTs, only two have formal charters.

b. Documenting a Program's Reliability Management Approach

In order to provide visibility into the management and organizational structure of those responsible (on both the government and contractor side) for the conduct of reliability activities in a program, there should be definitive documentation on all reliability activities, functions, processes, test strategies, measurement/metrics, data collection, resources and timelines required to ensure reliability system maturation.

Each PMO was asked how is the system reliability program was formally documented within their program. Responses are provided in Table 8 below.

Survey Responses:

Reliability Documentation Within PMO	Program Responses	% of Programs
Reliability Program Plan	3	17%
Contract Statement of Work (SOW)	12	67%
Test and Evaluation Master Plan (TEMP)	6	33%
Single Acquisition Management Plan (SAMP)	2	11%
No Formal Reliability Management Plan	15	83%
Other	6	33%

Table 8. Types of Reliability Documentation Within a PMO

Summary: The majority of responses indicate that, although reliability is addressed throughout various program documentation, there is no one single, guiding document, e.g. a “Reliability Program Plan” that provides a comprehensive compendium of program reliability activities. It should be noted that there is no requirement for PMs to have such an overarching document, but some in fact do. Of 18 programs surveyed, 83% (15 programs) had no formal Reliability Program Management Plan. Most rely on the contract SOW and the TEMP, or other documentation to address such things as how they intend to ensure reliability is treated as high priority objective, methodologies used to measure and project reliability, resources needed to execute the program, and future plans for monitoring reliability in the field.

Illustrative Examples:

1) Thermal Weapon Sight (TWS). During the solicitation process, offerors were required to submit a Quality Validation Plan (QVP) outlining how they proposed to assure reliability and other specification requirements. This QVP became part of the contract after contract award. Because of a number of reliability problems experienced by TWS, a Reliability Assurance Plan was developed to address the management approach for assuring reliability is maintained throughout production. The

approach includes reliability testing, and development of metrics to track key performance subsystems that directly effect reliability.

c. Reliability Growth in a Program

Reliability growth is the improvement in a reliability parameter over a period of time due to changes in product design or the manufacturing process. Some programs use a risk reduction method referred to as a Test-Analyze-Fix-Test (TAFT) as reliability growth, however, a structured reliability program is typically devised with specific interim reliability goals and test events. Managing reliability growth entails a systematic planning for reliability performance achievement as a function of time and other resources, and involves controlling the ongoing rate of achievement by reallocation of resources based on comparisons between planned and assessed reliability values. [Ref. 22] Reliability growth management techniques are typically employed on complex systems that use state-of-the-art technologies where the requirements for reliability, maintainability and other performance parameters are highly demanding. All survey participants were asked whether their program incorporates a reliability growth program (RGP). Where applicable, responses were further broken out in accordance with the reliability performance achieved during their reliability qualification Test (RQT) initial operational test (IOT). Survey responses are provided in Table 9 below.

Survey Responses:

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	33%	3	1	2
No	67%	2	8	2
N/A				

Table 9. Reliability Growth Programs

Summary: Reliability growth is an iterative design process. As the design matures, testing is performed and planned intervals to identify actual or potential

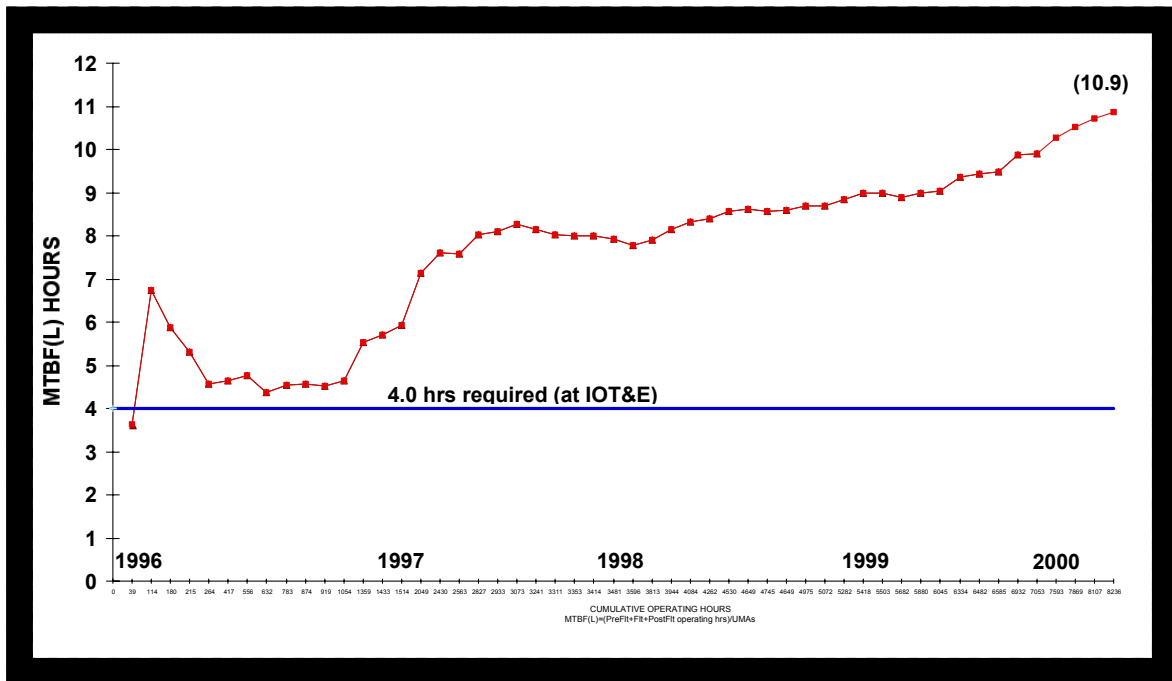
sources of failures. The intent is to gain knowledge and learn from early design mistakes, and then focus on fixing these as early as possible. For PEO IEW&S, two-thirds of all programs (12 of 18) surveyed did not initially implement a reliability growth program. After experiencing problems in either RQT or IOTE, these numbers have generally reversed, with nearly two-thirds of all programs now employing some type of growth program. Note the high correlation of reliability-related problems during testing with those that did not initially incorporate a RGP.

Illustrative Examples:

1) BCIS RDGT. The BCIS program employed a RDGT strategy that took into account factors such as constraints based on available test hours, time to implement fixes, and availability of test assets. The program derived the number of test hours required to demonstrate with confidence, the requirement of 1380 hours MTBEFF given test resources of three BCIS units for four months and an estimate of the expected number of failure that would be experienced. Appendix B provides a summary of the Program Offices approach in an information paper, *BCIS Reliability Development Growth Test (RDGT) Strategies*. [Ref. 23]

2) The Hunter TUAV Reliability Growth Success Story. The Hunter TUAV System has been in operation since 1991. As a result of all the FRACAS data collected over the years the Hunter Reliability IPT has made some smart decisions based on a Reliability Growth Management Plan that have allowed the system MTBF to “grow” three-fold from 3.6 to 10.9 hours, and the an 85% Ao to a 98% Ao. During system acceptance testing in 1995, several Hunter air vehicles were lost, due to various failures that resulted in a decision to terminate the follow-on production program. The Army wanted to benefit as much as possible from the substantial investment made, so an “end to end” Failure Mode Effect and Criticality Analysis (FMECA) and a Fishbone Analysis was performed on all the critical subsystems to identify the root causes, with resultant corrective actions implemented. The Hunter system is still flying today, in support of training base activities at the National Training Center (NTC) and Joint Readiness Training Center (JRTC), contingency operations in the Balkans, and in support of TUAV

advanced payload demonstrations. For more complete details on *The Hunter TUAV Reliability Growth Success Story*, see Appendix C of this report. [Ref. 24]



Source: PM TUAV, Huntsville, AL

Figure 3. Hunter TUAV Reliability Growth

d. Tracking and Measuring Reliability Performance Progress

A well-known saying contends: “you cannot manage what you do not measure.” PMs were asked to address the methodologies used to measure and track reliability in their programs. This is particularly important in reliability growth programs, as projection methodologies not only serve to ascertain requirement compliance, but as a means of identifying potential problems early in the process. Thresholds, or intermediate benchmarks representing minimum reliability achievement levels should be established at different points along the program as risk mitigation measures. A breach of one of these thresholds is a signal that the program is not on track to meet reliability requirements, and some form of intervention to rectify the problem is required. Table 10 provides answers to the survey question “How do you measure and track reliability performance progress overtime in your program?” Respondents were asked to check all that applied.

Survey Responses:

How is Reliability Performance Progress Measured and Tracked?	Program Responses	% of Programs
By contractor projections/analysis	7	39%
Reliability growth tracking methodology	3	17%
At major reviews (PDR, CDR, TRRs, etc...)	9	50%
By testing (e.g. RQT, RD/GT, ESS, IOT, etc...)	6	33%
Other (warranty, or TBD for new programs)	2	11%

Table 10. Measuring and Tracking Reliability Progress

Summary: All programs use some means to monitor reliability performance progress of their system during development. Albeit, the list of possible methods and opportunities for measuring and tracking reliability progress generated for this survey question are not all encompassing, the responses indicate that programs rely heavily on their contractors for indicators of reliability growth.

Illustrative Examples:

1. SGF program. For the SGF program, reliability conformance inspections are conducted annually on TIS and CITV throughout production

3. Policy, Procedures and Guidance

Objective: The DoD 5000.2-R states that the “PM shall establish RAM activities early in the acquisition cycle.” AR 70-1 continues by requiring an “R&M program will be tailored in scope and content and be designed to ensure that the user operational reliability requirements will be met at confidence levels established by the user.” Finally, DA PAM 70-3 guidance covers aspects of R&M Requirements, R&M Management, R&M Engineering and Design, R&M Testing, and R&M and Assessment Integrated Process Team (IPT) procedures. The question posed to PMOs was “Are you aware of any specific DoD or Army policy/regulation regarding weapon system reliability management? If yes, do you use it to help you manage reliability?” Answers provided in Table 11 help to determine the level of awareness of reliability policy, regulations and procedures, and whether these are sufficient to help a PM manage reliability performance in a program.

Survey Responses:

Reliability Policy Awareness?	Program Responses	%
YES	8	45%
NO	4	22%
NOT SURE	6	33%

Table 11. Awareness of Policy, Procedures, and Guidance

Additional responses are paraphrased below:

- Given the acquisition reform process, it is difficult to identify which policies/regulations for reliability are applicable at any given time.
- I am aware of DA PAM 750-40, *Guide to Reliability Centered Maintenance (RCM) for Fielded Systems*, however, this may not be the best guidance to give a contractor until the later stages of development.

Summary: Slightly over half of those individuals responsible for managing reliability performance are aware of, or not sure of existing policy and regulations. Those that answered in the positive cited the following policies and regulations as ones that they still use or refer too: AR 70-1, AR 73-1, DA PAM 73-1, and (guidance only) MIL HDBK 781, MIL STD 1635, MIL STD 785, MIL HDBK 217, MIL STD 470, MIL STD 1629, MIL HDBK 189, and ISO 9001.

F. INFLUENCING RELIABILITY REQUIREMENTS

Purpose: The next series of answers address reliability in the context of inputs to the requirements generation process. The purpose of these questions was to explore whether a reasonable and cooperative process existed, and if requirements for reliability were set arbitrarily or not. A secondary line of questioning explored the relative importance of reliability with respect to other key performance parameters in the ORD.

1. Influencing Realistic Reliability Requirements

Objective: The intent of the next question was to determine if the MATDEV is involved in influencing development of realistic reliability requirements into ORDs. A criticism of the defense acquisition process is that weapon system requirements are either not adequately defined or are unrealistic with respect to the state-of-the-art. The challenge becomes one of stating the reliability requirements in terms of operational mission needs and success under given conditions, with defined mission profiles and durations. Table 12 provides a summary of responses with respect to how PMs were able to influence this process for PEO IEW&S programs. Table 13 provides a summary of the types of reliability measures found in program ORDs. Note that some programs use more than one parameter to describe reliability related requirements of a system.

Survey Responses:

Ability to Influence Reliability Requirements in the ORD?	Program Responses	%
YES	14	88%
NO	4	22%
Other		

Table 12. Influencing the Requirements Process

Reliability Parameters in ORDs	Programs	%
MTBSA	6	33%
Ao	5	28%
MTBOMF	7	39%
% Prob Completing Mission w/out EFF	1	6%
MTBEFF	3	17%
MTBOMA	1	6%
MTBMAF	1	6%

Table 13. Reliability Parameters in ORDs

Summary: A large majority of programs do participate with the COMBATDEV as part of an Integrated Concept Team (ICT) to derive appropriate ORD requirements, including those related to reliability as part of the RAM rationale process. This is not universal, however, as there were 4 respondents that claimed reliability requirements were developed without the MATDEV's input. A review of reliability requirements in various ORDs also shows that there is not a standard lexis of how reliability is expressed in terms of operational terminology.

Illustrative Examples:

1) ACS ORD. The ACS program completed Concept Exploration and transitioned to Component Advanced Development (CAD) in early FY02. During the CE phase, competing contractor teams were required to perform a sensitivity analysis on the aircraft range requirement and associated reliability to see what the O&S cost implications were due to the fact that the airframe capabilities are the largest cost driver in the program. They also present the best opportunity for cost savings, and so the intent of the PM was to have the contractors provide airframe recommendations that comply with all other ACS Key Performance Parameters (KPPs), but may require alternate wording of the KPP associated with the airframe capability. The current requirement is that the ACS must be capable of self-deploying 2500 NM unrefueled with any mission payload, and initiating operations immediately upon arriving in theater, and sustaining operations for a minimum of fourteen days. Possible alternate wording is that the airframe be self-deployable worldwide within a fixed timeframe and with increased reliability.

2. Reliability As a Key Performance Parameter (KPP)

Objective: Key Performance Parameters (KPPs) are those ORD capabilities or characteristics considered essential for mission accomplishment. Failure to meet an ORD KPP threshold can be cause for the system selection to be reevaluated or the program to be reassessed or terminated. The intent of this next line of questioning is to determine the relative importance given to reliability performance in ORDs, and to assess where it stands in terms of requirements "tradespace." Table 14 provides responses of the 18 PEO IEW&S systems as to where in their respective ORDs the reliability requirement ranks.

Survey Responses:

ORD RELIABILITY REQUIREMENT			
KPP	Band "A" Priority	Band "B" Priority	Band "C" Priority
3	9	1	5
17%	50%	5%	28%

Table 14. Reliability Requirements in the ORD

Summary: Two-thirds of all programs surveyed have reliability prioritized in the ORD as either a KPP or in Band “A”. Lower priority does not necessarily mean less importance. It may be that the maturity of the technology is well known, such that reliability requirements are easily achievable, and therefore of less concern compared to other critical, less mature performance parameters of the system.

G. CONTRACTING AND INCENTIVIZING FOR RELIABILITY

Purpose: The next series of answers are in response to questions concerning how reliability is handled in the source selection and contracting process.

1. Reliability Requirements in Contracts

Objective: The first question focuses on how to address reliability requirements in contracts. The first survey question regarding this assessed two issues: 1) the significance of reliability in the source selection process; and 2) the method of translating operational ORD reliability requirements into quantifiable and verifiable contractual terms. The second question addresses whether or not specific reliability incentives are employed, and if so, whether the incentives are achieving their desired effect.

Survey Responses:

RELIABILITY AS A FACTOR IN SOURCE SELECTION	
YES	NO
50%	50%

Table 15. Reliability as a Factor in Source Selection

The second part of this question asked how operational reliability requirements in the ORD are translated into contractual requirements. Responses are summarized in Table 16.

TRANSLATION OF ORD RELIABILITY REQUIREMENTS TO CONTRACTUAL REQUIREMENTS		
ORD Requirement Restated in SOW	5	28%
Additional Levels Applied to Contract	13	72%

Table 16. Translation Between Operational and Contractual Requirements

Summary: Half of those programs that participated in full and open competition used reliability as a factor or sub-factor in source selection. Of those that did, only half found reliability to be a significant discriminator in the decision process. Several Night Vision programs viewed reliability as a “best value” item. One program, the JTT/CIBS-M, deemed reliability as not a significant factor since the program relied on a ten year warranty and 72 hour turn-around time to meet the Ao.

In terms of translating operational requirements to contractual ones, most programs add additional levels onto the reliability requirement to account for bench test/chamber in-house testing vice operational testing in the field and there are varied methodologies for doing such. Some increased the requirement by a factor of 2 to account for simulated operational environment is a DT test. Twenty-eight percent of programs, however, simply restate the ORD requirement in the contract SOW or Specification.

Illustrative Examples:

1) Translation of Operational Requirements to Contractual Requirements. This example from the BCIS program illustrates one method used for deriving a contractual reliability requirement from an ORD reliability value. This methodology is based on MIL HDBK 781. An ICT consisting of HQ TRADOC, the MATDEV, and Army Evaluation Center (AEC) RAM personnel determined the BCIS ORD MTBOMF requirement to be 1242 hours based on similar equipment capabilities. Starting with the

1242 hours ORD value, approximately 10% is then added based on AEC RAM military field studies for electronic equipment to get to 1380 hours. Next, a reasonable consumer/producer risk level of 20% each is apportioned to get the proper statistical confidence levels and this provides a contractual value of 2760 hours. The stated design goal of 3450 hours adds a calculation factor of approximately 20% for lab versus final field performance histories. Finally, the value was nearly doubled to around 6500 because two BCIS are required to complete an interrogation. BCIS achieved 3255 Hrs MTBOMF and thus exceeded the ORD requirement for multiple tank battles. [Ref. 25]

2. Contracting Incentives for Reliability

Objective: Providing meaningful contract incentives for achieving stated reliability performance is a potential method for motivating contractors. The objective of this question was to determine if reliability incentive methods were being employed and if in fact they were, did they achieve their desired effect.

Survey Responses:

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	1	6%	--	--	1
No	17	94%			

Table 17. Reliability Incentives in Contracts

Summary: An extremely low percentage of contracts (only 6%) include reliability incentives. Of the 18 programs surveyed, only one employed reliability incentives in their contract. The one program that did, the Prophet program, deemed it too early to tell if these incentives achieved their desired effect based on field data. Prophet did, however, exceed its reliability requirement in operational testing.

Illustrative Examples:

Good reliability is critical for unmanned systems. The Shadow UAV system which is currently in LRIP, plans to implement a reliability incentive contracting approach for its follow-on full rate production contract. The PMO is currently assessing

different incentive methods to motivate the contractor to continuously improve reliability after fielding through an incentive fee tied to achieving or exceeding failure rate goals, operating dollars/flight hour goals (power-by-the-flight-hour), or attainment of full mission capable rate goals. The benefits of incentivizing reliability improvement include shared risk, increased availability, reduced inventory level, and an environment that encourages continuous process improvement.

H. “DESIGNING-IN” RELIABILITY UPFRONT

Purpose: The responses that follow provide insight into the types of tools techniques, and process that PMs and their contractors employ to address reliability early on in the development of a system. “Designing-in” reliability up front in a system reduces risk and is less costly, as opposed to finding design issues later on at the “back end” during testing and validation. The point is that you cannot guarantee reliability due to robust test programs, you must proactively address it in the upfront design of a system.

Objective: The intent of this next question is to assess the types of design tools and methodologies employed by PMs as best practices to “design-in” reliability upfront in a program. Table 18 provides a summary of the survey responses.

Survey Responses:

Types of Design Tools Used to "Design-in" Reliability Upfront in a Program	Program Responses	%
Physics of Failure (PoF)	1	6%
Critical Items List/Analysis	8	44%
Identification of Known Problem Areas	14	78%
Software Reliability Assessment	7	39%
Quality Function Deployment	2	11%
Parts Control Program	5	28%
FMECA/FRACAS/FTA	8	44%
Reliability Prediction Analysis	3	17%

Table 18. Reliability Design Techniques and Methodologies

Summary: Emphasis should be placed early on in the use of proper design tools and activities to “build in” reliability up front. There are numerous reliability design tools/techniques that can be used to ensure reliability requirements are realized. Responses indicate that the primary method used by PEO IEW&S programs is “identification of known problem areas” and other available design tools and techniques are being sporadically utilized by PMOs.

I. DEVELOPMENT AND OPERATIONAL TEST EXPERIENCES

Purpose: Testing is the final validation of reliability performance requirements. The next series of answers are in response to questions concerning: 1) the adequacy of available time (schedule) and resources dedicated to reliability; 2) the types of testing conducted during development to continually assess progress and gain knowledge in terms of achieving reliability goals; 3) general agreement on reliability measures for test; 4) whether “gates” are established or entrance criteria imposed on systems before entering an operational test; and 5) an assessment of whether success in early reliability testing correlates with reliability achieved in the actual operational test of a system.

1. Resources

Objective: PMs continually make trade-off decisions in terms of cost, schedule, performance, and supportability in order to achieve overall program objectives. Often, a PM does not have adequate time or dollars to do the necessary levels of reliability testing to achieve confidence in the system. To get a sense of this for PEO IEW&S programs, survey participants were asked whether the amount of time and funding allotted for reliability testing was sufficient for their programs. Responses are provided in Table 19.

Survey Responses:

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
3	9	6
17%	50%	33%

Table 19. Adequacy of reliability Resources in a Program

Summary: The majority response was that PMs, in general, could use more time and dollars if available to reduce reliability risks. Programs that responded otherwise were either fielded systems that had a minimal reliability program, or programs early on in development. It is towards the end of development and prior to formal testing, when time and dollars become scarce, that programs tend to adjust reliability efforts downward.

Illustrative Examples:

1) Thermal Weapon Sight. Reliability testing is unfortunately often traded off for cost and schedule. During the TWS Engineering and Manufacturing Development (EMD), the PM went directly to the OT without completing the contractor reliability test in order to meet cost and schedule goals. The net result was that the system achieved less than 10% of the reliability requirement, and the OT was changed to a LUT, with follow-on OT being required. In production on this same program, the contractor chose a one-failure test plan for the RQT in order to meet cost and schedule. The end result was five RQT attempts later, the TWS finally passed. The contractor failed to adequately consider the risks associated with the chosen test plan, thus chose a high risk plan in an attempt to meet schedule and reduce test costs.

2) Second Generation FLIR (SGF). During the SGF EMD phase, the original contract had both an RDGT and an RQT were initially planned. The program ran out of time and dollars and had to rebaseline, and so the RQT was changed to a fixed length demonstration test of 2,000 hours, and separate RDGT was eliminated and basically combined with the fixed length test. Although the tank sights did not meet established reliability, the most critical sub-element, the SGF HTI B-Kit, did have very good performance, exceeding the requirement in OT. The overall reliability performance was accepted “as-is” after significant cost and schedule impacts. [Ref. 26]

2. Testing to Determine Reliability Performance Compliance

Objective: In theory, reliability performance of a system should be continually assessed throughout its lifecycle. Programs sometimes fall into a common trap of assuming reliability is what the contractor states it to be, or reliability is treated as “final

exam” rather than a sequence of test events to learn from. The focus of this next question is to establish what types of test activities PMs use to determine reliability performance progress and compliance in a program. Results are summarized in Table 20.

Survey Responses:

Types of Test Activities PMs Use to Determine Reliability Performance Progress & Compliance	Program Responses	%
Environmental Testing/ESS	17	94%
Accelerated Testing (e.g. HALT)	7	39%
Reliability Development Growth Test (RDGT)	7	39%
Reliability Qualification/ Demonstration Test (RQ/DT)	11	61%
Government Development Test (DT)	8	44%
Operational Testing (e.g. LUT/ OPTEMPO/IOTE/FOTE	16	89%
Acceptance Test/Production Verification Test	2	11%
Maintenance Demonstration	2	11%

Table 20. Test Activities Used to Determine Reliability Objectives

Summary: Environmental Tests, Reliability Qualification Tests, and Operational Tests are the three primary venues used by PMs to determine progress and compliance with respect to reliability performance. Some of these tests, for example environmental testing, can be conducted separately, as part of a Government DT, or post-production as part of a lot-sampling acceptance test technique.

3. Agreement on Reliability Measures for Test

Objective: It is extremely important to have a common understanding by all parties (PM, User, Contractor, and Tester) on the relationship between the contractual reliability and the operational reliability requirements of a system. The fact is that reliability parameters expressed by operational Users and ones specified in contractual documents take on many different forms, and so there needs to be a general understanding of the crosswalk between the two. The CBTDEV will typically define reliability in terms of operational availability and mission duration needs, while the

MATDEV in turn takes these parameters and allocates them to technical reliabilities of systems and subsystems, i.e. MTBF or other similar measure. The challenge of a PM is to ensure the contractual reliability of the system, usually measured in controlled conditions, supports the very dynamic and many times unpredictable environment in which operational reliability is measured. Getting that right is crucial to the success of a program. Given the above, survey participants were asked if all parties (PM, User, Contractor, and Tester) were in agreement with the method (model) used to determine reliability performance during testing. Survey responses are provided in Table 21.

Survey Responses:

Have the PM, User, Contractor, and Tester Agreed Upon Common Terms for Measuring Reliability ?	Program Responses	%
Yes	12	67%
No	4	22%
Not Sure	2	11%

Table 21. Agreement on Reliability Measurement for Test

Summary: Two-thirds of all programs in fact, do have agreement between all parties concerning the appropriate reliability measures for test.

4. Initial Operational Test & Evaluation (IOTE) Entrance Criteria

Objective: One approach for maximizing the chances for successfully meeting reliability requirements in IOTE with the requisite level of confidence (usually 80%) is to establish entrance criteria for a system. This can be a self-imposed risk reduction approach by the PM, or many times is required by the independent Tester/Evaluator to ensure that the system has a reasonable probability (reasonable probability defined here as greater than or equal to 50% of successfully passing its IOTE. Striving to meet reliability entrance criteria implies you are testing reliability in DT or in other test events and have a well laid out developmental effort, with emphasis on reliability designed “up-front” and sufficient testing programmed to mature and validate required reliability levels. All those surveyed were asked if their program had specific IOTE entrance criteria with respect to reliability. Survey responses are provided in Table 22.

Survey Responses:

Does Your Program Have Reliability Entrance Criteria for IOTE ?	Program Responses	%
Yes	10	56%
No	7	39%
Not Sure	1	5%

Table 22. Reliability Entrance Criteria for IOTE

Summary: A significant number, 56% of programs surveyed have or had reliability entrance criteria established with respect to IOTE. Some of those that did not indicated that reliability performance results achieved during DT and at other test events were briefed at Operational Test Readiness Reviews (OTRRs).

Illustrative Examples:

1) Shadow TUAV. The IOTE entrance criteria varied, depending on the program. For example, the Shadow TUAV system must demonstrate the ability to operate for 12-18-18-18-8 hours over a 5 day period in accordance with its OMS/MP. The JTT-CIBS-M program must demonstrate successful progress in its RDGT. Still yet, other programs within PM NV/RSTA have entrance criteria requirements in terms of MTBOMF and MTBEFF with varied levels of confidence. In some programs, for example BCIS, there were no IOTE entrance criteria with respect to reliability due to the fact that there were not enough hours in IOTE to be a statistically significant event for reliability.

5. Correlation of Early Test Results with IOTE Success

Objective: Testing early and often for reliability, within the fiscal realities of a program's budget, is key to gaining early knowledge and is used for correcting deficiencies in a system prior to its operational test event. Survey participants were asked whether prior success in reliability performance testing during DT or other events correlated with a success in IOTE. Responses are summarized in Table 23.

Survey Responses:

			Level of ORD Reliability Requirement Demonstrated	
Correlation of Early Reliability Test Results With IOTE Results?	Program Response	%	Initial DT Results	Initial OT Results
Yes, success in pre-IOTE reliability testing led to requirements being fully met in initial IOTE.	5	28%	100%	100%
			8	5
Not completely, system did well in pre-IOTE testing but had some problems in initial IOTE	1	6%	80%	80%
			4	3
Not at first, system passed IOTE after <u>X</u> attempts.	5	28%	60%	60%
			2	
N/A , system either not yet involved in an operational test or the OT did not assess reliability.	7	38%	≤ 40%	≤ 40%
				3

Table 23. Correlation of DT Reliability Testing with OT Success

Summary: Programs that experience success in pre-IOTE reliability testing do not always enjoy success in IOTE. Of the 18 systems surveyed, 7 had either not yet gone through their operational test, or the amount of operational test hours was not sufficient enough to be statistically significant to evaluate reliability. Of the remaining 11 systems, five did not successfully pass their IOTE on their first attempt, with problems at least partially attributed to reliability issues. In one program, the system had fully demonstrated its reliability requirement during DT and other testing, only to achieve around 40% of its requirement once it went to OT.

Illustrative Examples:

: A number of PEO IEW&S programs experienced reliability problems during their initial (and some subsequent) operational tests. Some examples follow.

- The Shadow TUAV system entered into an IOT in Apr 01. After two air vehicles crashed early on the test was reduced to a Limited User Test (LUT) and subsequently halted. System performance was due to a combination of factors: training, crew errors, and reliability problems. Prior to the IOTE, Shadow had fully achieved its MTBSA requirement of 20 hours in an OPTEMPO test conducted prior to IOTE that also demonstrated the ability to meet its OMS/MP of 12-18-18-18-8 hours over a 5-day period. Reliability during the shortened IOTE was assessed by the Project office at approximately 8 hrs MTBSA.

- The Common Ground Station achieved only 11 hrs MTBSA vice its requirement of 48 hrs in its first operational test. The system improved some during its second OT, and finally met its reliability requirement in the third OT.
- The Thermal Weapon Sight (TWS) failed its IOTE in February '00, and four subsequent RQTs before finally passing on its fifth attempt.

J. THE IMPACT OF ACQUISITION STREAMLINING AND DOWNSIZING

Purpose: With the advent of acquisition reform came a strong push towards achieving the most efficiency possible by “reengineering” the way we do business in the defense acquisition environment. Military specifications and standards were no longer acceptable and performance-based contracting became the best practice. During the same period, government downsizing occurred and doing more with less was the norm, and so the question must be asked, is there a downside to this at all? Perhaps not, but to get a sense of the pulse from those in the reliability community the question was put forth.

Objective: The focus of this question was to get feedback and opinion from people who work reliability performance management within the PMOs to see if there has been any perceived adverse effects with respect to reliability due to the shift to performance specifications, increased use of COTS, and government downsizing. The responses in Table 24 represent the opinions of those that participated in the survey.

Survey Responses:

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.	7	39%
Yes, due to downsizing the workforce.	2	10%
Yes, due to both acquisition streamlining and downsizing	7	39%
No	1	6%
No comment	1	6%
COTS/NDI components do not live up to OEM claims	3	17%

Table 24. The Impacts of Acquisition Streamlining and Downsizing

Additional Survey Comments (Paraphrased):

- The Government is losing/has lost reliability expertise at the PMO level. Also, using COTS products increases risk in the area of reliability for weapons platforms in a military environment.
- The inability to state specifically the reliability tools and the level of detail desired allows a contractor to minimize their reliability effort.
- The Government has lost the majority of the expertise to manage reliability effectively and acquisition reform has resulted in vague requirements that cannot be demonstrated by contractors.
- There has been a complete turnaround with regards to the importance of DEMONSTRATING reliability requirements. Not enough time or money to accomplish requirements that have no backing.
- Reliability testing is too expensive and cannot be adequately resourced. We (PM) do not have enough qualified personnel to be dedicated to reliability, plus, we do not follow up after the system is fielded to track failures.
- A COTS approach does not necessarily equate to high reliability in a military environment.
- Restrictions in the ability to specify the test method sometimes results in an inappropriate methodology being employed which has to later be negotiated out of the contract. Also, the requirement to state reliability as a probability resulted in a number of problems as well.

Suggestions for Improvement from Survey Respondents (Paraphrased):

- Allow the government to place the hard reliability requirements back in the contracts language.
- Reinstate the RAM rational process; issue binding policy for reliability; state reliability in terms demonstratable by contractors; require reliability program plans; hold PM's (as part of their rating) accountable for reliability; make reliability a KPP; and budget adequate funds for reliability.

Summary: There are some strong emotions concerning this subject. A significant majority of respondents (89%) are of the opinion that acquisition streamlining and/or workforce downsizing have in some way contributed to the state of reliability within the Army today. Reasons given include loss of government expertise in the area of reliability, inappropriate use of COTS in a military environment, and lack of resources dedicated towards reliability. Approximately 40% of respondents believe the Army community must compensate with alternative policies, processes, and tools.

K. COMMERCIAL PRACTICES

Purpose: The focus of this survey question is to see what best commercial practices in reliability assurance are being applied to the acquisition of military systems.

Objective: The responses summarized in Table 25 establish the type and extent of commercial best practices employed by program management offices.

Survey Responses:

What Types of Commercial Reliability Assurance Practices Do You Employ in Your Program?	Program Responses	%
Physics of Failure (PoF)	1	6%
Predictive Models	3	17%
Prognostics/Life Consumption Monitoring	--	0%
Identification and Mitigation of Failure Modes (e.g. FMECA)	4	22%
Accelerated Life Testing (e.g. HALT)	3	17%
Reliability Growth Testing	6	33%
Reliability-Driven Parts Selection/Control	5	28%
Other	--	0%
Do Not Employ any Commercial Practices	5	28%

Table 25. Use of Commercial Reliability Assurance Practices

Summary: Most programs (72%) in general employ some type of tools or techniques using commercial best practices and methods to assure that high reliability products can be manufactured.

L. MAINTAINING AND IMPROVING RELIABILITY IN THE FIELD

Purpose: AR 70-1 states that “PMs are to track fielded system’s failure and repair histories starting at First Unit Equipped (FUE).....and should focus on the identification of operating and support cost drivers that lead to improvements where they are cost effective.” The next series of questions in the survey were posed to determine the extent to which PMs track and manage reliability performance post-fielding, and whether a data collection system is in place to support focused and cost effective improvements once a system is fielded.

Objective: The responses are intended to demonstrate whether PMOs are adequately engaged in tracking and improving a fielded system's reliability. Table 26 summarizes the survey responses in six separate areas: 1) conditional materiel release; 2) formalized system for collecting field reliability data; 3) status of reliability performance in the field; 4) cost effective reliability improvements in O&S; 5) formal reliability improvement programs; and 6) Reliability Centered Maintenance (RCM).

Survey Responses:

RELIABILITY OF FIELDDED SYSTEMS				
	YES		NO	
	#	%	#	%
Conditional Materiel Release (CMR)				
Was the system initially fielded with a CMR due to reliability shortfalls?	2	20%	8	80%
Is the CMR still in effect?	1	10%	1	--
N/A	--	--	8	80%
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	40%	6	60%
Warranty collection data provides information on reliability performance	3	30%	7	70%
A formal collection system does not exist	6	60%		
Status of Reliability in the Field				
System performance meets/exceeds ORD	4	40%		
System performance is less than ORD	--	--		
Do not know (due to lack of data, or too early)	6	60%		
Cost Effective Reliability Improvements				
Has collection of reliability failure data in the field led to any cost effective improvements?	3	30%	5	50%
Too early in program to tell	2	20%		
Reliability Improvement Program				
Is there a formal reliability improvement program?	1	10%	9	90%
Reliability Centered Maintenance (RCM)				
Is there a formal RCM program?	--	0%	10	100%

Table 26. Reliability of Fielded Systems

Summary: It appears as if there is a general lack of a systematic process for collecting reliability trend data. You can repair or warranty data on most any system either through contractor logistic support or the Army maintenance databases, but there is no process in place to actually go in, examine reliability trend data, and feed that data back in to the contractor for corrective action. Of the ten fielded PEO IEW&S systems surveyed, 60% do not have a formal reliability data collection system in place. It is not surprising then, that 60% also do not know if fielded system performance is meeting the ORD requirement. Only 30% of the systems use field data to implement cost-effective changes that improve reliability. Only one program has a formal reliability improvement program, and none have a Reliability Centered Maintenance program.

Illustrative Examples:

1) SGF Program. In the SGF contract, quarterly failure review boards are held to examine all the field return data, and address corrective actions.

2) Image Intensification (I2) Systems. Production Quality Deficiency Reports (PQDRs) are a formalized system and a means for soldiers in the field to report a problem or issue, and give feedback on systems. One drawback is that this method generally takes 6-8 months to close out. After the system gets sent back to vendor, it is investigated, and a corrective action is applied if necessary or warranted. Most soldiers in the field, however, do not fill out a PQDR if the I2 tube is still under warranty. Some may not know about the system or feel it is too much trouble to fill out.

3) Hunter UAV. The Hunter program implements a RAM system that includes:

- Failure Reporting, Analysis and Corrective Action System (FRACAS)

The prime contractor maintain a closed loop FRACAS. The FRACAS database is available on-line to the Government. Failures involving flight critical performance or safety impacts have priority for corrective action. The prime contractor establish and maintain on-line files to track the status of high priority corrective action requests derived from FRACAS activities.

- RAM Data Assessment

The prime contractor/Government performs assessment of the RAM data available in the FRACAS database. Assessment are limited to failure characterization.

- Failure Review Board (FRB)

The prime contractor/Government jointly conduct FRB meetings on regular intervals (with intervals established by Government and contractor in the IPT) to review failure data and to track high priority failures through the FRACAS process. The FRB evaluate reported failures for criticality of performance and safety impact and establish priority for corrective action.

M. CHAPTER SUMMARY

This chapter provided data gathered from surveys, interviews, and information collected from various PMs within the PEO IEW&S organization. These programs provide a fairly representative cross-section of experiences with respect to weapon system reliability performance management due to their diversity in ACAT levels and acquisition phases. The survey addressed 20 questions regarding important issues with respect to reliability management, with responses grouped into eight main themes for ease of data presentation. The responses provided good insight into the practices employed by each PMO on how they manage reliability performance risks in their programs. Furthermore, survey responses were augmented with some examples of reliability program management experiences to illustrate real-world challenges and concerns that PMs are often confronted with in dealing with managing the reliability “tradespace” of weapon systems.

The next chapter discusses the eight main reliability themes and focuses on key issues, barriers, and risk mitigation techniques and strategies for maximizing the inherent reliability performance of weapon systems. The analysis is aligned around the research questions in Chapter I and based on respondent’s answers presented in this chapter.

IV. RELIABILITY MANAGEMENT ISSUES, ANALYSIS AND LESSONS LEARNED

A. INTRODUCTION

This chapter provides an analysis of central issues that are common to PMs with respect to achieving weapon system reliability performance, and evaluates the general “state of reliability” within PEO IEW&S. The analysis is based on current program data and survey responses provided by participating PMOs, and is structured around the eight reliability management themes described in Chapter III. Lessons learned based on background data and information derived from survey responses is provided at the end of this chapter.

B. KEY RELIABILITY MANAGEMENT ISSUES

Poor system reliability can be the cause for significant schedule delays and program overruns, and also have debilitating effects on warfighting readiness. While this research focused specifically on weapon systems developed by PEO IEW&S, the issues portrayed and the resultant findings may be generally be applied to a broader set of programs throughout the Army and DoD. For the purposes of this thesis, analysis of the issues related to reliability are presented in accordance with the eight reliability management themes as described in Chapter III:

- Management Approach to Reliability
- Influencing Reliability Requirements
- Contracting and Incentivizing for Reliability
- “Designing-in” Reliability Upfront
- Development and Operational Test Experiences
- The Impact of Acquisition Streamlining and Downsizing
- Commercial Practices
- Maintaining and Improving Reliability in the Field

C. ANALYSIS OF KEY RELIABILITY MANAGEMENT ISSUES

1. Management Approach to Reliability

So why do we struggle with reliability? Why do our weapon systems trend towards failure more often than success when it comes to achieving their reliability requirements? The state-of-the art technology that we deal with for certain can be cited as one factor, but not the driving one in my opinion. Yes, it is true that the night vision systems that we integrate on ground combat systems have complex optics and intricate focal plane arrays, and air vehicle platforms relegate their own set of reliability challenges on our sensor systems, and our systems must operate in harsh environmental conditions, but is that really it? The limits of technology and the capabilities it brings to our systems are expanding each year, and so that must be recognized, but in the larger analysis, it all come down to how we manage.

Key Reasons Why We Fail. The survey responses citing the “Top 10” Army reliability issues, and answers to the other survey questions for that matter, center around 5 main causes, all of which have more to do with lack of proper managing than they do with technology challenges:

- Unrealistic Requirements – There is a dialogue disconnect between the MATDEV and the CBTDEV on reliability requirements.
- Poor Planning – Reliability growth is not widely utilized as a tool to reduce reliability related design issues early on.
- Overall Poor Design – Reliability is not being “designed-in” upfront in our weapon systems.
- Inadequate Testing – Testing is too little/too late and is typically shortchanged as funds and schedule become tight.
- Lack of Qualified Personnel – Downsizing has left a gap in qualified reliability experts.

The following paragraphs are some additional key noteworthy points”

Responsibility. Who is responsible for reliability within a PMO? Two-thirds of all programs surveyed address issues related to reliability in either a Reliability Integrated Product Teams (IPT) or a Logistics IPT. This may not necessarily be a positive thing, as this could effectively be *isolating* reliability engineering to only those IPTs. Instead,

reliability should be the responsibility of *all* IPTs to get at the actual sources of the problem, rather than have one IPT addressing only the symptoms.

Planning & Documentation. Only a small percentage (17%) of programs within PEO IEW&S have a comprehensive document that identifies details of a Reliability Program Plan (RPP) for their system. Of those that do have one, none were reviewed for content as part of this thesis research, but a good plan should detail all of the reliability activities, functions, processes, test strategies, measurement/metrics, data collection, resources and timelines required to ensure system reliability objectives are achieved within the program.

Reliability Growth. Two-thirds of all programs surveyed do not utilize reliability growth testing (RGT) as mechanism for continuously gaining knowledge on their system. The reality is that reliability performance is not always continuously assessed, or worse yet, the emphasis on reliability oftentimes comes too late in a program. One example is a program where the contractor's engineering estimates and models were accepted as fact, and no formal reliability testing was ever conducted. In another, reliability was not assessed until the IOTE event, and the results were well below the requirement and hence the system failed. Still another did not initially assess reliability until very late, at their first RQT. All sadly had the same results, and due to lack of early testing, it cost these programs valuable time and money to correct the problems, perhaps even more so than had they invested upfront. A reliability growth approach allows a program to demonstrate trends towards achieving reliability objectives, and implementing corrective actions early on while the design is still not yet locked in. The opposite of that is true if you wait until IOTE or an RQT to test reliability, both of which are "fixed" configuration tests that are more of final exam than a useful learning event.

Tracking Reliability Progress. If an RGT program is not employed on a program, other methods must be used to measure progress towards reaching the reliability objective. For PEO IEW&S, the majority of programs track reliability progress by either using contractor projections, test events, or major program reviews. This may be a prudent approach for those systems that are incorporating COTS/NDI components, but

for other programs that are pushing the envelope with respect to state-of-the-art, reliability must be tracked and managed at a more detailed level.

2. Influencing Reliability Requirements

From the data gathered on the 18 systems, it appears that for the most part there is a healthy dialogue between the PM and the User with respect to reliability inputs into the requirements process. This is somewhat in conflict with results of the “Top 10” list from the same pool of respondents that ranked “unrealistic reliability requirements/rationale” as the #5 problem. The reason for this may be because that while there is an exchange on reliability between the two communities as well as the test community, it may be a less formal process than once previously practiced. Requirements are no longer developed as part of RAM working groups that were the comprehensive basis or rationale for the numbers.

ORD Reliability Parameters. According to DoD 5000.2-R, reliability requirements are to address *mission* reliability and *logistics* reliability. By definition this implies that ORD reliability requirements should focus on measures related to completing a mission, and minimizing logistics demands. Only 7 of 18 (39%) programs within PEO IEW&S have reliability measures tied to an operational availability requirement. The other programs have stated reliability requirements that are primarily performance parameters and are not tied to mission or supportability measures such as operational readiness/availability, reduced logistics footprint, manpower, and spares levels for example. Part of the systemic problem is having the COMBATDEV define something that in reality is up to the MATDEV to allocate through the system engineering process. The COMBATDEV focus should be on defining acceptable levels of *mission* failure while leaving the technical solution and reliability thereof to the MATDEV.

Reliability as a KPP. Reliability is not regarded in the same fashion as traditional performance factors in that very rarely is reliability ever identified as a Key Performance Parameter (KPP) of a system. Only a three (17%) of PEO IEW&S programs had reliability identified as a KPP in the ORD. There are several possible reasons why this may be so. One is that both the CBTDEV and MATDEV may feel it is too early in a program life cycle to designate a definitive KPP tied to reliability. Another reason may

be that mandating reliability as a KPP reduces a PMs precious trade space and constrains the PM's flexibility.

3. Contracting and Incentivizing for Reliability

Translating ORD Requirements to Contractual requirements. If ORD requirements fall short regarding definition of reliability expectations, then the chances are the contract reliability requirements will be just as inadequate. There must be a clear "link" between operational and contractual reliability, one that allows for conclusive and accountable proof of results. The challenge is to crosswalk contractual reliability requirements (typically assessed in a static environment, contractor's plant, controlled test/climate) with operational reliability requirements (measured in a dynamic environment, soldiers operating the system, dirty battlefield). Failure to do this will significantly increased risk of program failure. It is clear that in order to achieve the reliability required in the ORD requires a higher reliability to be specified on contract. This helps to account for the environment human and environmental differences between lab testing and soldiers operating systems in the field. However, that being said, 5 out of 18 programs that participated in the survey simply restated the ORD requirement as the contract requirement. This approach could have considerable downstream consequences, whereby the demonstrated levels of reliability performance could fall significantly short of the stated ORD requirement.

Contract Incentives.

If we truly are concerned about reliability performance of weapon systems, it is not obvious or evident in our current contracts. Only 1 of 18 programs within PEO IEW&S is currently even considering a contracting strategy that has incentives tied to achieving reliability performance objectives. This is a dilemma in that we are not incentivizing the behavior we seek from our contractors. It may be a cultural thing, or perhaps we don't know how to adequately incentive performance in this area. There simply does not seem to be a willingness to explicitly pay for reliability, almost as if reliability were assumed as a given. This is a mindset that we must overcome; otherwise contractors will continue to have no motivation to produce higher reliability systems.

4. “Designing-in” Reliability Upfront

“Designing in” reliability implies performing upfront analyses during the design phase so that the inherent reliability of the system is as high as possible. Examples of this include: 1) reducing the number of overall parts in a system can improve its reliability by decreasing the number of moving mechanical parts; 2) incorporating redundancy; 3) analyzing potential failure modes and mitigating the effect of failures or incorporating graceful degradation features; 4) doing a part stress analysis, and 5) making sure all of the chosen parts are de-rated properly. These are only but a few examples. As with anything else, theoretically, being proactive with reliability early in the lifecycle of a system is more cost effective than dealing with potential schedule delays and unexpected costs of failing a test later, only to have to redesign, and test yet again until the problem is fixed. All programs in the survey utilize some form of design tool or techniques to optimize reliability early on in a program. The “goodness” of these tools and technique was not evaluated, however.

5. Development and Operational Test Experiences

Reliability does not always have the emphasis, resources, or attention it requires to ensure mission success in a program. As evidenced by one night vision program, PMs are often forced to tradeoff reliability when their program is squeezed for schedule or is tight on funds. The “saved funds or schedule” are usually “bought” back later when problems arise in the system.

Entrance Criteria. Over half of the programs surveyed had IOT&E entrance criteria tied to demonstration of specific reliability performance. Whether this is a mandate from higher leadership, or self-imposed by the PM, it is a good practice to abide by. To be relevant, demonstration of reliability performance should adequately duplicate the Operational Mode Summary/Mission Profile that is expected in the operational test. ATEC statistics find that 61% of programs that successfully demonstrate their reliability requirement prior to operational test enjoy a 65% success rate (meeting reliability requirements) during the actual OT. Conversely, those system failing to achieve reliability requirements prior in DT have an 82% failure rate in OT. The bottom line is, demonstration of reliability requirements in DT or other early test events can enhance the chances for success in OT. An analysis of PEO IEW&S systems does not support this

hypothesis one way or the other. Twenty-eight percent of programs that had reliability performance successes in DT prior to IOTE went on to pass the test event, and 28% failed their IOTE event after successful DT testing.

6. The Impact of Acquisition Streamlining and Downsizing

Although subject to much debate for sure, and granted responses to this line of questioning are opinion rather than fact, an overwhelming majority felt that acquisition streamlining, workforce downsizing, and use of COTS all had some level of influence on reliability. This is purely a qualitative rather than quantitative assessment, based on the personal views of those surveyed. Eighty-eight percent of all survey responses were of the opinion that acquisition streamlining and downsizing had some negative effect. Examples cited include:

- Loss of reliability technical expertise as a consequence of both natural attrition and government imposed reductions.
- Lack of definitive contract requirements for use of reliability tools
- Reliability performance gets “lost” in trade space.
- Concerns with how to define enforceable performance-based reliability requirements.
- Reliability testing has been marginalized due to cost constraints and personnel cuts.

Rather than blame acquisition reform and changes in how we do business today for current reliability shortfalls, it is more appropriate to recognize the need for increased training, alternative policies, new processes and tools.

7. Commercial Practices

Best commercial practices in reliability include physics of failure, predictive technologies, prognostics/life consumption monitoring, identification and mitigation of failure modes/mechanisms (FMECA), accelerated life testing, growth testing, and selection of reliable parts to name a few. None of these commercial practices appear to be utilized to any great extent in the 18 programs surveyed. Greater use of these tools will reduce the risk of test failure, decrease the need for retest, and minimize corrective actions.

8. Maintaining and Improving Reliability in the Field

The Army measures reliability after fielding by using different terms for availability rates; 1) operational availability, and 2) fully mission capable. Operational availability (Ao) has been previously defined as the probability that an item is in an operable and committable state at the start of a mission when the mission is called for at a random point in time. A system is fully mission capable (FMC) when it can perform all of its combat missions without endangering the lives of crew or operators. The terms ready, available, and full mission capable are often used to refer to the same status; equipment is on hand and able to perform its combat missions. FMC percent is total available days divided by possible days and multiplied by 100. The problem with this measure is that you can have an artificially high mission capable rate with excessive sparing, at the sacrifice of a larger logistics footprint. What really is needed to get a true indication of reliability performance in the field is a combination of FMC with MTBM or mission reliability with logistics reliability.

As discussed in the previous chapter, and reinforced by the above, there appears to a disparity of how to measure and collect reliability information from the field. Most PEO IEW&S programs do not have a formal system in place, and rely on sporadic feedback from the field, CLS records or PQDR information. The problem is that this data is not reviewed or tracked adequately for reliability trends. Another concern is that there does not appear to be any significant formal reliability improvement initiatives in place.

D. LESSONS LEARNED

Based on the survey responses and reliability information provided by PEO IEW&S systems, lessons learned can be extracted.

1. Understand the Requirement

A clear understanding ORD reliability performance measures as they relate to mission performance and system readiness is required in order to be successful in a program. This then needs to be translated into contractual reliability requirements that are measurable, enforceable, and traceable back to the operational requirement.

2. “Design in” Reliability

Achieving reliable, available and maintainable systems requires a disciplined systems engineering approach that starts early on in a program. You cannot “test in” reliability no matter how hard you try. Do not just leave reliability up to the engineering or the logistics disciplines, everyone must be involved in the process.

3. Test Early, Test Often

Managing reliability growth requires continuous testing at planned intervals to gain knowledge and mature the system to ensure successful achievement of reliability performance objectives.

4. Check the Underlying Process

Reliability issues are not always strictly due to the uniqueness of the program, or technology, or management issues. Check the underlying manufacturing design process of the contractor their vendors to ensure that they are measurable and repeatable.

5. Prove It

Predicted reliability performance tends to be overstated. Apply a null hypothesis to these reliability claims, i.e. that they are untrue until proven otherwise in the form of a valid test results with confidence in the numbers. This does not mean test for testing sake, because that can bankrupt your program. Use available data if it is applicable to your system. Always have a contractor prove his/her reliability claims.

6. Maintain a Balance

High reliability must be balanced with achieving other programs objectives in terms of cost, schedule and performance. Too much reliability can cost just as much as too little reliability. The challenge is to maintain a balanced perspective when performing tradeoffs.

7. Follow Up

Reliability focus does not end with fielding. Feedback from the field concerning reliability performance is not an automatic thing. Think ahead and plan for how you are going to collect failure data to identify reliability trends and areas for improvement.

E. CHAPTER SUMMARY

This chapter analyzed current PM practices, issues and challenges in managing the reliability performance of weapon systems based on program data and results of a reliability performance survey. The analysis was structured around eight reliability management themes and attempted to pinpoint either best practices to implement in a program, or common pitfalls that PM should avoid. Lessons learned were then provided based on these experiences and the background data gathered as part of this research. The final chapter will make some recommendations on how to best approach reliability performance from a management perspective.

V. CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

Research conducted in support of this thesis evaluated the present process for managing weapon system reliability performance and identified some of the common challenges, pitfalls, and lessons learned encountered by Program Managers today. The issues and challenges were derived from surveys, interviews, and information provided by PMs within the PEO IEW&S organization.

In this closing chapter, conclusions with respect to the management of weapon system reliability performance are identified as a result of feedback and analysis of survey responses. In addition, the author makes several recommendations with respect to practices and strategies that PMs can employ to maximize the inherent reliability performance of weapon systems. Next, brief answers to the primary and secondary research questions are provided. Finally, this thesis concludes by providing recommended areas for further study.

B. CONCLUSIONS AND RECOMMENDATIONS

Analysis of survey results, interviews and program data provided by PMO personnel involved in reliability have led the researcher to the following conclusions and recommendations:

1. Reliability Program Plan

Conclusion: Programs in general, do not have a structured reliability management process or a corresponding overarching document that defines the activities, schedules, test strategies, and resources required to provide effect management insight into achieving overall reliability objectives of a program.

Recommendation: Require all PMs to develop a Reliability Program Plan (RPP) that explicitly defines reliability management responsibilities within the organization; related tasks, activities, and processes; test and verification methods; schedule and resources necessary to achieve reliability system maturation. This should be considered a mandatory document for all Milestone Decision reviews, similar to what

a Test and Evaluation Master Plan (TEMP) provides in identifying the overall program test strategies and resources, or a Command, Control, Communication, Computers, and Intelligence Support Plan (C4ISP) that details a roadmap for achieving interoperability certification of a system.

2. Continuous Reliability Assessment

Conclusion: Programs do not utilize reliability growth techniques and often test too little, too late with respect to reliability performance.

Recommendation: DoD should re-evaluate the requirement to achieve certain technology readiness levels (TRL) in programs by certain milestones and incorporate additional criteria linked to reliability maturity levels.

3. Requirements Clarity

Conclusion: The current process for establishing operational reliability performance measures in requirements documents is inconsistent, and does not always link reliability performance to mission or supportability measures as required by DoD 5000.2-R. This can lead to confusion between the MATEV and CBTDEV and result in failure to achieve overall desired readiness levels.

Recommendation: Establish standards for defining reliability measures in ORDs, and reinstate the RAM rationale process to ensure that MATDEVs and CBTDEVs are jointly defining realistic achievable reliability requirements. Establish a mechanism that requires traceability of contractual reliability performance requirements to operational reliability requirements.

4. Reliability as a Key Performance Parameter (KPP)

Conclusion: Reliability often times gets shortchanged and is traded off to meet cost, schedule and performance objectives.

Recommendation: Consider making reliability a KPP for certain programs where appropriate.

5. Incentives

Conclusion: Programs do not adequately incentivize contractors to meet or exceed contract reliability requirements.

Recommendation: Develop standard contract language that truly incentivizes a reliability maturation process throughout a system's lifecycle. Incentives could be tied to a series of reliability growth demonstrations as the design matures, i.e. beginning with reliability predictions, then RDGT, achieving reliability entrance criteria to IOTE, demonstrating success at RQT, and through field metrics such as sparing levels or warranty returns. After implementing this language, identify a pilot program to participate and apply this to

6. “Design in” Reliability

Conclusion: Programs do not adequately take advantage of commercial tools and techniques for “designing in” reliability upfront in a program. Done properly, this is where significant downstream program savings can be achieved.

Recommendation: DoD should consider partnering with commercial firms that develop and employ these tools.

7. Reliability Entrance Criteria

Conclusion: Programs often fail to achieve reliability objectives during operational testing due to inadequate upfront reliability testing.

Recommendation: Establish a standard IOTE reliability entrance criteria methodology for programs and make it part of the Operational Test Readiness Review (OTRR) process.

8. Reliability of Fielded Systems

Conclusion: Most programs do not have a formal process for collecting reliability trend information from the field.

Recommendation: DoD should fund and establish a standardized system for accomplishing this.

C. ANSWERS TO RESEARCH QUESTIONS

Primary Research Question: What essential steps can a Program Manager take to better manage weapon system reliability requirements over a program's life cycle, and how can reliability performance be maintained and/or improved once the system is fielded?

The following are recommended steps a PM should consider taking in an effort to better manage weapon system reliability performance:

- Make sure there is a common understanding between the Program Office and the User on what the reliability requirement means in the ORD.
- “Design in” reliability early on in a program. Do not hope to “test in” reliability later. It simply does not work that way.
- Plan for incremental testing to control reliability growth and gain knowledge for incorporation into the system design as it matures
- Do not shortchange reliability testing for the sake of cost or schedule. It will bite you back later.
- Make sure what you contract for in terms of reliability performance adequately supports the operational reliability performance requirement of the system.
- Have a solid plan.

Subsidiary Research Questions: The following subsidiary questions focused the author's efforts in answering the primary research question.

1. **What are the predominant underlying factors that contribute to reliability performance in Army systems, and how can a Program Manager (PM) mitigate risk in these areas?**

There are 5 main causes, which contribute to poor reliability performance:

- Unrealistic Requirements – There is a dialogue disconnect between the MATDEV and the CBTDEV on reliability requirements.
- Poor Planning – Reliability growth is not widely utilized as a tool to reduce reliability related design issues early on.
- Overall Poor Design – Reliability is not being “designed-in” upfront in our weapon systems.

- Inadequate Testing – Testing is too little/too late and is typically shortchanged as funds and schedule become tight.
- Lack of Qualified Personnel – Downsizing has left a gap in qualified reliability experts.

2. What are the current policies and regulations that govern reliability of weapon systems, and do they provide PMs with adequate guidance?

The current policies and regulations that govern reliability of weapon systems include DoD 5000.2-R, AR 70-1, and DA Pamphlet 70-3. They all do a fairly good job with respect to addressing policy and procedural guidance on reliability and maintainability (R&M) requirements with regard to weapon systems.

3. How does the Army address reliability performance of a weapon system in the requirements generation process, and to what extent can a PM influence this process?

Reliability requirements are developed by the CBTDEV in conjunction with the MATDEV as part of an Integrated Concept Team Process that the PM participates in. Three key elements combine to define overall reliability performance requirements: 1) operational and logistics reliability parameters; 2) the OMS/MP of the system; and 3) failure definition and scoring criteria. A PM can influence this process by participating in the IPT and providing reliability realism in terms of what the current state-of-the-art is.

4. How is reliability addressed in the system engineering process, and what technology, tools and techniques are available to ensure reliability of a system is "designed in" upfront?

The starting point for designing in reliability is the systems engineering process beginning with requirements definition and analyses, and the conduct of cost/benefit trade-off analyses to determine alternative requirements, allocations, and design

solutions. Examples of the types of technology, tools and techniques that are available to include the following:

- Physics of Failure (PoF).
- Critical Items List/Analysis.
- Identification of Potential Reliability Problems. .
- Software Reliability Assessment. .
- Redundancy.
- Variability Production Processes & Quality Assurance. .
- Parts Control Program.
- Allocation and Prediction.
- FMECA, FRACAS, and FTA.

5. How has acquisition reform and the shift to performance based contracting impacted the reliability of weapon systems?

Although there is mixed opinion on their effects on reliability, acquisition reform and performance based contracting have allowed the contractor the flexibility to determine exactly how the reliability requirements will be achieved. They do not give the contractor relief from the requirement, it still must be met.

6. To what extent does commercial industry differ in their approach towards product reliability, and can the Army leverage these best practices to improve performance in military systems?

There are numerous differences between the needs of the military customer and those of the commercial customer, the reliability needs of the military focus primarily on operational readiness (product performance on demand), operational longevity (long useful life vs. short life cycles), operational supportability (repair/replace vs. throwaway items), and operational robustness (satisfactory performance over environmental extremes. Industry typically tests for reliability early and continuously throughout the

development cycle of a product. The Army, on the other hand tends to treat reliability like a final exam, and should embrace the commercial industry philosophy.

7. How is system reliability addressed as part of the test program, and what program strategies can a PM employ to ensure that a system will successfully pass reliability testing with a high level of confidence?

Reliability should, in practice, be tested throughout the test program of a system. The key is to test early and test often. Various contractor and government tests can be used to demonstrate compliance to contractual and operational reliability requirements:

- Environmental Testing
- Accelerated Testing
- Reliability Development/Growth Testing (RD/GT)
- Reliability Qualification/Demonstration Testing (RQ/DT)
- Government Developmental Testing (DT)
- Operational Testing (OT)
- Early User Test(EUT)/Limited User Test(LUT)
- Initial Operational Test (IOT)
- Follow-On Test (FOT)

8. How do PMs plan to manage and track reliability, and what metrics are useful for measuring reliability performance during various stages of system development?

PM manage and track reliability via contractor testing, reliability growth tracking methodology, through major design review, testing, and by collecting field data. Typical reliability measures include MTBSA, MTBOMF, MTBEFF, MTBOMA, MTBMAF, and Ao.

9. How does a PM contract and incentivize for reliability with industry, and are there potential areas for improvement?

This is not a widely used practice, and is one that needs to be pursued further. Incentives could be tied demonstrations of reliability growth, and successful achievement of a systems reliability requirement during a major test.

10. Once a system is fielded, how does a program office ensure reliability performance is maintained, and what further can be done to improve reliability performance of fielded systems?

PMs can ensure reliability of a system is maintained by setting up a system that collects and tracks reliability failures in the field. One technique for improving reliability performance in the field is to identify cost effective reliability improvements and incorporate through system upgrades.

D. RECOMMENDATIONS FOR FURTHER STUDY

The following are recommended topics for additional research:

- Evaluate how and what kind of reliability data is currently collected in the field, and determine how to best optimize the process so that there is proper feedback for reliability improvement.
- Analyze the best methods and approaches for incentivizing reliability in contracts
- Compare and contrast the commercial model for achieving highly reliable systems with that of the DoD. Assess how this can be best adapted for weapon system development.

E. THESIS SUMMARY

Managing weapon system reliability performance demands constant attention and implementation of effective management strategies that balance cost, schedule and performance against reliability risks over the course of a weapon system's development and fielding. The key to it all resides in early identification of upfront cost-effective opportunities for improving reliability performance, and mitigation of associated risks during design, manufacturing development, test, and post-production. Predictability in the field is the desired end state.

Reliable weapon systems are a critical element to fighting and winning wars. To put this all in perspective, at the U.S. Army Forces Command (FORSCOM), where warfighting readiness is the number one priority and their soldiers are "on point for the nation", their primary mission is to train, mobilize, and deploy ready ground forces in support of the National Military Strategy. FORSCOM has openly stated that in order to support their number one requirement of readiness, they require predictable weapon systems. That need for predictability equates to a requirement for reliable systems.

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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 Program Executive Office for Intelligence, Electronic Warfare & Sensor (PEO IEW&S). 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 30 Nov 2001. A separate survey is required to be filled out for each participating program.

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

Project/Program Management Office:select here (click on dropdown list)

Program/System Name:select here (click on dropdown list)

Current Life Cycle Phase:

- ☐ 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 (MS phase as defined under the old 5000 model)

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

- ☐ ORD (state value e.g. 300 hrs MTBF, 95% A_O)
- ☐ 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% A_O)

- ☐ 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 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
☐ 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 IOTE, 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-IOTE reliability testing led to reliability requirements being fully met in IOTE
☐ Not completely, system did well in pre-IOTE reliability testing, but had some new problems during IOTE that needed correcting
☐ Not at first, system passed IOTE 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 IOTE 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 “tradespace”?

- ☐ Highest tier priority/Band A
☐ Middle tier priority/Band B
☐ Lower tier/Band C or below

Additional comments:

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

- ☐ No, requirements were developed independently by COMBATDEV
☐ Yes, input was provided as part of ICT or RAM rationale 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 Army 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 Army 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 Army Top 10 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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APPENDIX B: BCIS RELIABILITY DEVELOPMENT GROWTH TEST (RDGT) STRATEGIES

1. **Purpose:** The purpose of this paper is to provide a preliminary strategy for development of a course of action for the BCIS RDGT to be conducted as part of PVT II for subject system. The paper provides some basic concepts relative to growth methodology, the parameters which define a growth curve (and thus growth test strategy); the sensitivities of those parameters to test length and the risk associated with various strategies. A feasible strategy is then fashioned within the resource constraints of budget and time given technical feasibility.
2. **Growth Parameters:** The formula for an idealized growth curve is given by:

$$(1) \quad M_f = [M_i / (1 - \alpha)] [(T / T_1)^\alpha]$$

Were: M_f = Final MTBF value we wish to grow to. (see note)

M_i = Initial MTBF of the system starting test.

T = Total number of test hours.

T_1 = Time to first failure; i.e., when our first fix will be implemented.

α = Growth Rate

Note: The M_f value represented by this formula is to achieve your reliability requirement at the point estimate level. It is desirable and standard practice to meet requirements with 80 percent confidence, which would then be the desired value to grow to; i.e., in order to demonstrate confidence, one must grow to a MTBF value higher than the requirement level. This formula does not allow for computation of final MTBF values at confidence levels and is given here for illustrative purposes. Computations on final MTBF values (i.e., meeting requirement with confidence) were done using AMSAA generated software routines.

3. **Calculation of BCIS Reliability Growth Parameters:** In order to determine test requirements for the BCIS RDGT, estimates for a number of growth parameters had to be constructed based on a number of factors: assumptions, historically feasible growth rates, current estimate of BCIS reliability, and limitations constrained on testing such as number of units under test, number of fixes to be implemented, and calendar time available for testing. Test duration is sensitive to the α growth rate, the requirement we wish to demonstrate with confidence, the starting or initial MTBF (M_i) and the expected elapsed time before we see our first failure and put in our first fix (T_1). Based on the calendar time available for test (4 Months) and units under test available (3), the maximum time available was computed at 8,640 hours. However some of that time must be allotted for implementation of fixes or corrective actions for failures found during the test, so that the reliability of the system may be matured. A growth rate of $\alpha = 0.45$ was assumed (based on historical data); this is an acceptable but high risk level for growth achievement, anything less would violate the calendar time constraints. A starting or initial MTBF (M_i) of 560 hours MTBEFF was assumed using reliability projection methodology and based on a Fix

Effectiveness Factor (FEF) of 95% on corrective actions to failure modes occurring during PVT several years ago (this area will be elaborated on subsequently). T_I is estimated (heuristically) at 2.5 to 3.0 times M_I (the foundation is: find a time interval, T_I such that we have a .90 to .95 probability of at least one failure occurring given an initial MTBF of M_I using a Poisson Distribution with mean $\lambda=(T_I/M_I)$). Figure 1 represents the idealized growth curve based on the above parameter construct.

BCIS RDGT Requirements

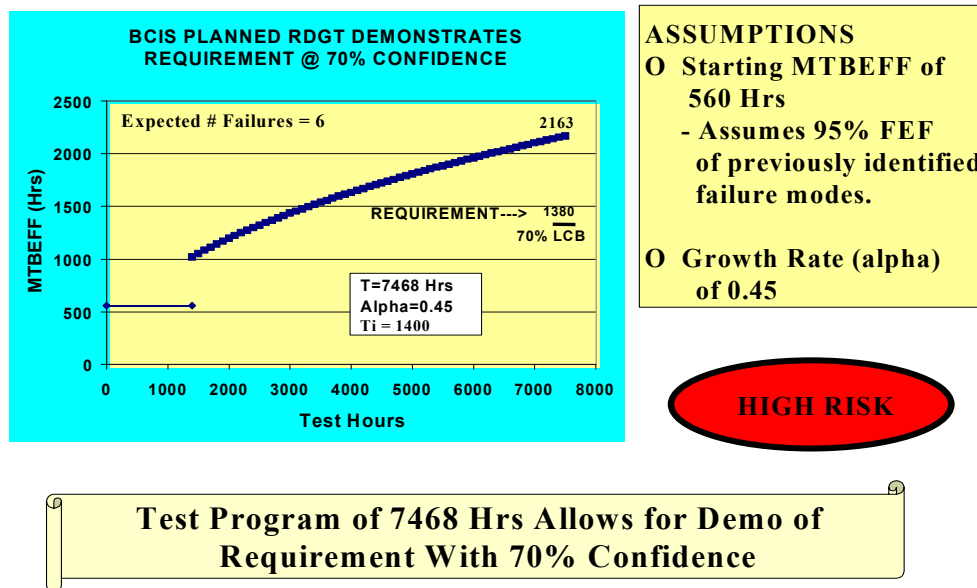


Figure 1. BCIS Technically Feasible RDGT Strategy

Figure 1 represents the idealized curve of a technically feasible RDGT strategy constrained by calendar time and test resources. This strategy calls for 7468 hours of testing (combined on three available units). The expected number of fixes was calculated as six. Given max available time and actual test hours, provides time for fix implementation. Given the achievement of a 0.45 growth rate and initial starting MTBEFF, the system can grow to a value of 2163 hours MTBEFF, thus meeting the contractual specification of 1380 hours MTBEFF with 70% confidence. Given the constraints mentioned, this is the maximum confidence allowable by this test (more on confidence later).

4. **Sensitivity of RDGT Hours to Initial MTBF:** Test duration is highly sensitive to growth rates and initial MTBF values. Obviously if we start out higher on the growth curve then test length can be decreased for the same growth rate or the growth rate can be decreased (lessor risk) for the same test length. The construct of the highly sensitive initial MTBF (M_I), was based on the application of reliability projection methodology to fixes implemented for failure modes occurring during PVT several

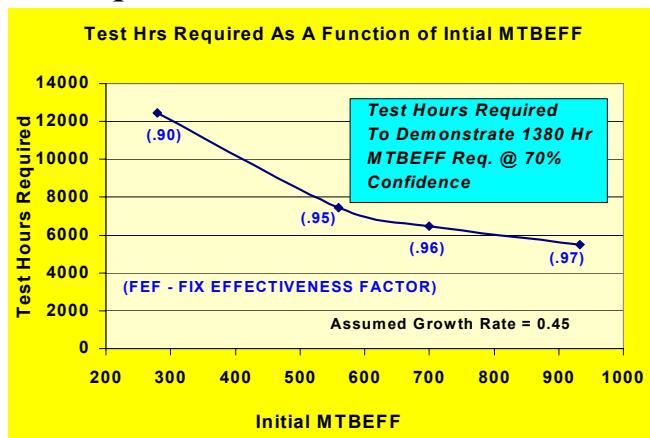
years ago. Actually the initial MTBF value computed represents the reliability “potential” of the system or theoretical upper bound of achievable reliability given a certain fix effectiveness for fixes implemented and no new failure modes occurring in the system (in effect a biased estimate since we never really test long enough to discover all the failure modes in a system). The short form equation for calculation of reliability potential is given as:

$$(2) \text{ Potential MTBF} = \frac{\text{MTBF (from PVT)}}{1 - (\text{MS})(\text{FEF})}$$

where: MS represents the Management Strategy or the percentage of failure modes to be addressed through corrective action. The MTBF value from PVT is 28.

The contractor in conjunction with the PMO took an aggressive stance w.r.t. corrective action implementation for failure modes occurring during PVT and addressed 100% of all failure modes (hence, MS goes to 1). Clearly, calculation of the potential MTBF (which will be our value for Initial MTBF (M_i) in the formulation of the growth test curve) is highly dependent on FEF which in turn impacts growth test length. Figure 2 provides an illustration of the sensitivity of our initial MTBF (M_i , which is dependent on FEF) on the test length needed to satisfy requirement compliance at the 70 percent confidence level.

Sensitivity of Test Hour Required For Requirement Demonstration to Initial MTBEFF



- O Required Test Hours Highly Sensitive To Starting or Initial MTBEFF
- O Initial MTBEFF Uncertain
 - Effectiveness of Fix from PVT
 - New Design
- O 95% Chosen as Fairly Aggressive FEF

FEF In Excess of 98% Requires Demonstration Test Not RDGT

Figure 2. Sensitivity of Test Lengths to Initial MTBF and FEF

Figure 2 shows the required test hours for various Initial MTBF values computed using formula (2). In parenthesis are the corresponding FEF used which produced the

initial MTBF value; e.g., a 0.90 FEF value corresponds to an M_I of approximately 280 hours, a 0.95 to our 560 hour M_I etc. Obviously, there is much uncertainty surrounding the calculation of this estimate. The fixes implemented appear to be very sound from an engineering perspective, but are they really that effective? The historical average FEF across all systems is about .7 or 70 percent; i.e., fixes are effective in reducing the failure rate of that particular failure mode by 70 percent. Albeit in programs such as Comanche an 81% FEF is achieved with some components (electronics) as high as 90-95%. There is also uncertainty as to the new design as well. Any FEF below 0.95 will not allow for a sufficiently high enough initial MTBF to allow reasonable requirement demonstration given our constraints; i.e., will significantly increase test hours. By the same token, if the fixes are highly effective (98%) and the design sound then an RDGT would not be necessary, only a RDT (Reliability Demonstration Test), at significantly less hours. However, this cannot be ascertained and the initial MTBF (M_I) becomes the single most critical parameter for this excursion.

5. **Confidence:** Figure 3 provides for a sensitivity of confidence versus test duration using the values given for M_I , T_I , along with our 0.45 alpha rate. As can be seen by figure 1, the cost for additional confidence is increased test hours, which will violate our schedule constraints; e.g., to demonstrate at 80 percent confidence will require approximately 9,000 test hours. It is felt that the current test length and confidence is sufficient for demonstration of the specification requirement of 1380 hours MTBEFF. Albeit, this requirement is indicative of the hardware/software reliability of the system, it is felt that demonstration with this level of confidence will provide enough “slack” to allow for any failure rate attributed to operator/maintainer inducement so that the operational requirement in the ORD may be realized.

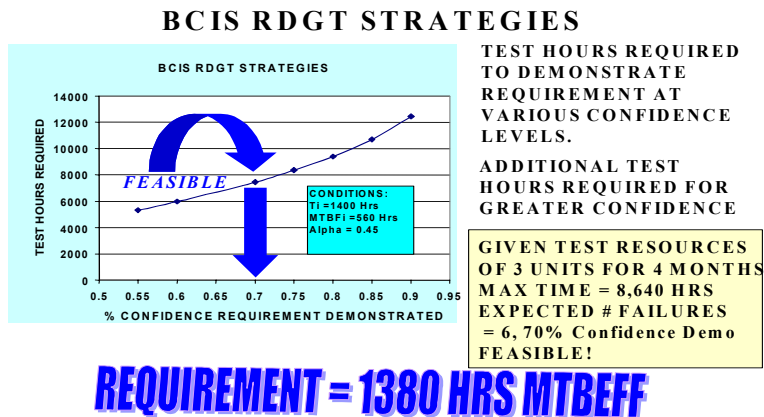


Figure 3. Sensitivity of Confidence Levels To Test Lengths

6. **Risk:** Assessing risk relative to an RDGT is dependent upon a number of factors: growth rate achievability, ratio of final MTBF to initial MTBF value, and the uncertainty surrounding the true initial MTBF (M_I). (1). Growth rate: A growth rate of 0.45 for continuous time systems is considered very aggressive. The average growth rate for developmental time/mileage (continuous) systems range from 0.30-0.30. (2). If the

ratio of our final MTBF to our Initial MTBF is greater than six, the program is considered high risk (based on AMSAA study). Our ratio is 2163/560 or approximately 3.9. Finally, the uncertainty regarding the estimate of our initial MTBF based on a FEF of 0.95 remains unascertainable. The risk is considered high.

7. **Summary:** Contained within is the basis for the construct of a feasible RDGT strategy which satisfy the constraints of available test hours, time to implement fixes, and availability of test assets. Given the technical aspects, this strategy (figure 1) is feasible, but high risk. Given success, it does provide for adequate levels of confidence relative to reliability requirement compliance. Additional details need to be worked relative to test conduct, mode of equipment operation, and temperature and vibration profiles.

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APPENDIX C: HUNTER UNMANNED AERIAL VEHICLE (UAV) SYSTEM RELIABILITY GROWTH STORY

15 Oct 2001

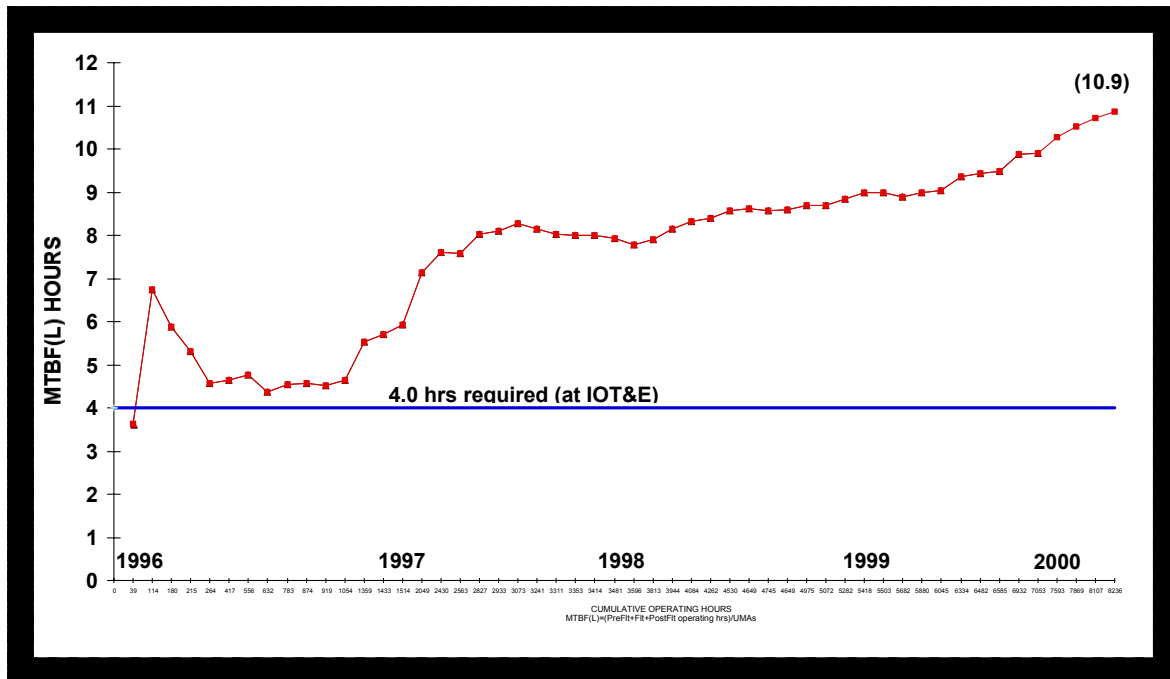


Figure 1. System MTBF(L)

ABSTRACT: This paper describes how the Hunter Unmanned Aerial Vehicle (UAV) System Mean Time Between Failure (MTBF) grew from 3.6 to 10.9 hours (Figure 1). To meet the U. S Army's urgent need for an UAV System, the Hunter System integrated existing technology without going through the normal development phase. Contract was awarded for Technical Evaluation Test (TET) in 1989 followed by a Limited User Test (LUT). Flight Competition occurred during 1990-1991 and the Low Rate Initial Production (LRIP) award was granted in Feb 1993.

During system acceptance testing in 1995, several Air Vehicles (AVs) were lost, due to various failures resulting in a decision to terminate the follow-on production program. However, the Army wanted to benefit as much as possible from the substantial investment made, therefore, the UAV-SR Program Management Office (PMO) and the TRW Program Office (the system prime Contractor) decided to perform an "end to end" Failure Mode Effect and Criticality Analysis (FMECA) and a Fishbone Analysis on all the critical subsystems - involving subject matter experts from each group, including all the major subcontractors. This process identified the root causes, developed technical

approaches and implemented corrective actions on the critical issues to get the program moving forward, and on a UAV program, that means getting and keeping AV's in the air flying (Figures 2 & 3).

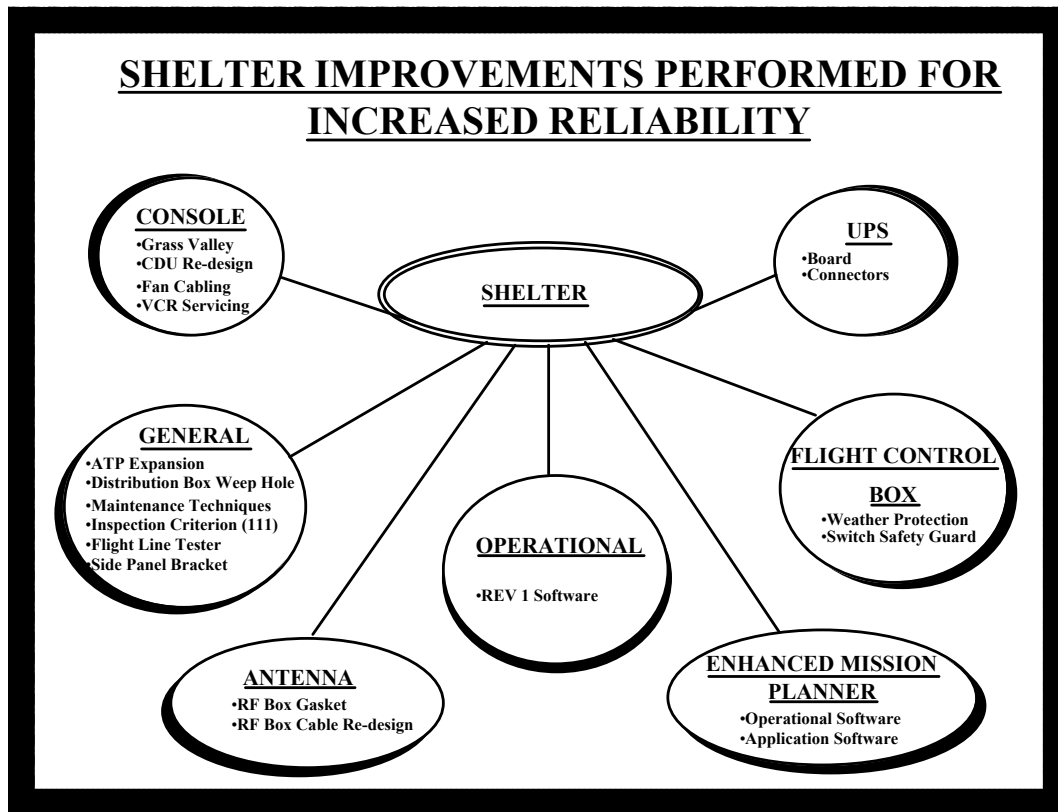


Figure 2. AV Reliability Improvements

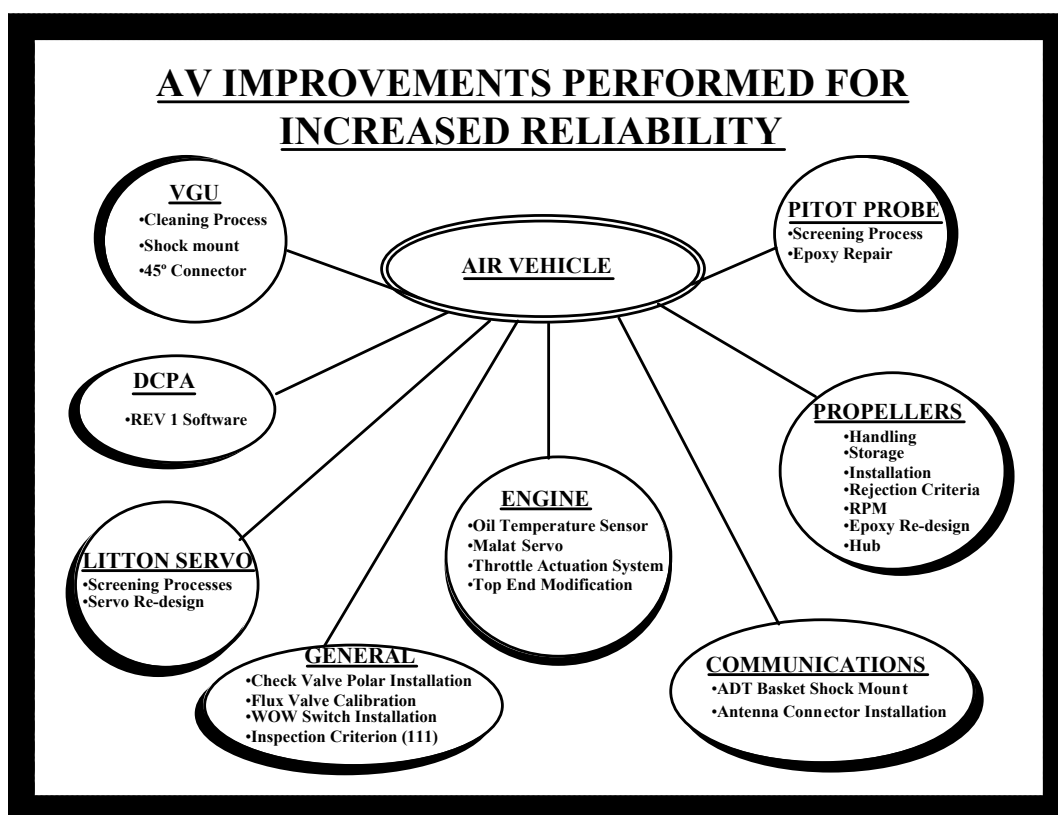


Figure 3. System Reliability Improvements

A decision was made to form an alliance with the senior technical representatives of TRW, Major Subcontractors, PMO, and the end item U. S. Army in an Integrated Process Team (IPT) forum for the following functions:

- Management IPT (PMO & TRW PM) – Overseer of the subtler IPT's and its effectiveness.
- Risk Management Council (RMC) IPT – Mitigates flight and safety risks.
- Failure Review Board (FRB) IPT – Provides visibility of trends.
- Aviation Safety Council IPT – Focuses on operational safety.
- Standard Evaluation Board for Operational Procedures (Technical Manuals – TM) IPT – Provides continuous updates and real-time information via field bulletins.
- Depot Operations (Supporting Fielded Assets) IPT – Prioritizes the use of assets to meet field needs.
- Engineering IPT (Design issues) – Prioritizes technical issues.
- Extended IPT (On-site) – Technical support team provided with each system deployed, along with a database management system for the users and technical support teams to collect failure information.

The organizational dynamics in forming the IPTs had dramatic effects. Involving the PMO, End Item Users, and Major Subcontractors, with the TRW program team in the identification of problems by developing technical approaches, setting priorities and designating limited resources, allowed everyone to take ownership in the course of actions. The effectiveness was so successful that the PMO institutionalized the process by incorporating the IPTs into their Statement of Works (SOW) in subsequent years.

The results of the system performance improvements continued to build the customers confidence level. Meeting the user needs and increasing the MTBF measurements, have been very significant:

- Deployment to the training base, Fort Huachuca, Az. 1995.

- Deployment to the first operational unit, Fort Hood, Tx. 1996.

- National Training Center (NTC) Demonstrations, 1996, 1997, 1998.

- Balkan Wars and Peace keeping forces, 1999, 2000.

- Deployment to Joint Readiness Training Center (JRTC), Fort Polk, La. 1999.

- Deployment to Interim Brigade Combat Team (IBCT), Fort Lewis, Wa. 2000.

- Providing a UAV platform for demonstration of effectiveness and proof of concept for U.S. Armed Services Payloads.

From 1996 through 2000, the Hunter UAV program has developed a very satisfied customer community by proving that a reliable UAV system, is in fact, a valuable asset to the U. S. Army's inventory. The Hunter approach to technical problems and success is a valuable lesson for any UAV program on customer satisfaction and reliability growth.

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9. PM UAV PAYLOADS
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