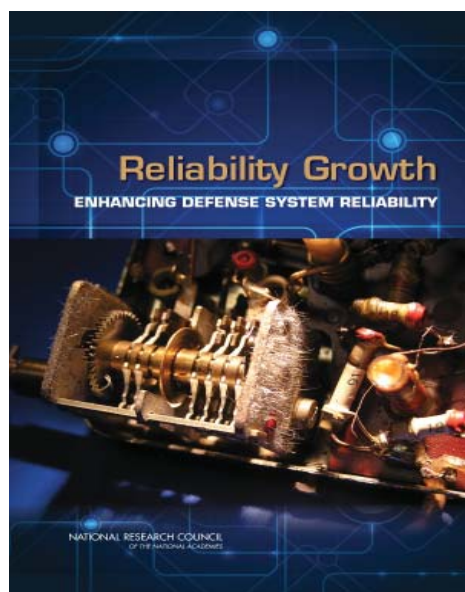


REPORT BRIEF

RELIABILITY GROWTH: ENHANCING DEFENSE SYSTEM RELIABILITY



Reliability is the innate capability of a system to perform its intended functions: it is one of the key performance attributes tracked during Department of Defense (DoD) acquisition. Yet the urgency to deploy new technologies and military capabilities often leads to defense systems being fielded without having first demonstrated adequate reliability.

Defense systems with poor reliability are not only less likely to successfully carry out their intended missions, but they may also endanger lives. Deficient systems are also much more likely to require extra scheduled and unscheduled maintenance and to demand more spare and replacement parts over their life cycles. In addition, not finding fundamental flaws in a system's design until after it is deployed can lead to costly program delays, expensive redesigns, and the imposition of operational constraints.

Reliability Growth: Enhancing Defense System Reliability (2015), a report from the National Research

Council, offers recommendations to improve defense system reliability throughout the sequence of stages that comprise DoD acquisition processes—beginning with the articulation of requirements for new systems and ending with feedback mechanisms that document the reliability experience of deployed systems. A number of these recommendations are partially or fully embraced by current DoD directives and practice, particularly with the advent of recent DoD initiatives that elevate the importance of design for reliability techniques, reliability growth testing, and formal reliability growth modeling. The report supports the many recent steps taken by DoD, building on these while addressing associated engineering and statistical issues. The report provides a self-contained rendition of reliability enhancement proposals, recognizing that current DoD guides and directives have not been fully absorbed or consistently applied and are subject to change.

A CHALLENGING ENDEAVOR

Today's DoD systems typically entail greater design complexities, more dependence on software components, increased reliance on integrated circuit technologies, and more intricate dependencies on convoluted nonmilitary supply chains than at any time in the past. Moreover, unlike industrial system development with a single project manager driven by a clear profit motive, DoD acquisition involves many "agents"—a system developer, one or more contractors

FINDINGS AND RECOMMENDATIONS: OVERVIEW

Developing reliable defense systems is an increasingly challenging endeavor.

Over the past six years, DoD has taken a number of essential steps towards developing systems that satisfy prescribed operational reliability requirements and perform dependably once deployed.

Fundamental elements of reliability improvement should continue to be emphasized, covering the application of:

- operationally meaningful and attainable requirements;
- requests for proposal and contracting procedures that give prominence to reliability concerns;
- modern design for reliability activities that elevate the level of initial system reliability prior to testing;
- focused test and evaluation events that grow system reliability and provide comprehensive examinations of operational reliability;
- appropriate applications of reliability growth methodologies—compatible with underlying assumptions—for determining the extent of system-level reliability testing and the validity of assessment results;
- empowered hardware and software reliability management teams that direct contractor design and test activities;
- DoD review and oversight processes; and
- feedback mechanisms that span reliability design, testing, enhancement initiatives, and post-deployment performance to inform current and future developmental programs.

Sustained funding is needed throughout system definition, design, and development:

- to provide incentives to contractors for reliability initiatives;
- to accommodate planned reliability design and testing activities, including any revisions that may arise; and
- to provide sufficient state-of-the-art expertise to support DoD review and oversight.

and subcontractors, a program manager, testers, oversight offices, and military users. Also unlike the commercial sector, where reliability risks are borne primarily by the manufacturer, for defense systems the government generally assumes most of the risk.

FUNDAMENTAL ELEMENTS FOR IMPROVING SYSTEM RELIABILITY

Requirements. Reliability requirements should be grounded in terms of operational relevance, explicitly linked to the costs of acquisition and lifetime sustainment, technically feasible, and measureable and testable. Reliability should be designated as a “key performance parameter.”

Request for Proposals (RFP). The government’s RFP should contain sufficient detail for contractors to specify how and at what cost levels they would

design, test, develop, and demonstrate system reliability.

Modern Design for Reliability. Building in high reliability early in system design is better than relying on extensive and expensive system-level testing later in development and post-deployment to correct low initial reliability levels. Modern design for reliability techniques include appropriate mixes of (1) failure modes and effects analysis, (2) robust parameter design, (3) block diagrams and fault tree analyses, (4) physics-of-failure methods, (5) simulation methods, and (6) root-cause analysis. For electronic components, current reliability prediction handbooks should be eschewed in favor of system-specific physics-of-failure methods and validated estimates.

At the preliminary stages of design, contractors should be able to build on the details offered in

RFPs and subsequent government interactions. Software-intensive systems and subsystems should be subject to special scrutiny, and holistic design methods should be used to integrate hardware, software, and human factors elements to address potential interaction failure modes.

Testing.

- **Test Plans.** Reliability test plans, both hardware and software, should be regularly reviewed (by DoD and the developer) and updated as needed, especially at major design reviews. Attention should be given to contractual requirements, reliability goals, and what remains uncertain about component, subsystem, and system reliability. Reviews need to consider testing conditions, especially since results from non-operationally representative environments can inflate reliability estimates.
- **Early Developmental Testing and Evaluation.** The primary goal should be to identify and address substantive reliability deficiencies early on, when they are least costly to address. For hardware components and subsystems, there are numerous “accelerated” testing approaches available to identify, characterize, and assess failure mechanisms (including long-term operational usage issues such as material fatigue, aging, and environmental effects) within the limited time available in early testing. They include exposing test articles to controlled nonstandard overstress environments and invoking physically plausible models to translate observed results to nominal use conditions. For software, contractors should be required to test the full spectrum of usage profiles and to implement meaningful performance metrics to track software completeness and maturity.
- **System-Level Reliability Testing.** When system prototypes (or actual systems) are produced, system-level reliability testing can begin, but that should not occur until the current system reliability is demonstrated to be compatible with the prescribed target in the program’s reliability demonstration plan. Individual test phases should be used to explore system performance capabilities under different combinations of environmental and operational factors. System-level testing should incorporate elements of operational realism to the extent feasible. At a minimum, a single full-system, operationally relevant developmental test event should be scheduled near the end of developmental testing and evaluation – with

advancement to fully realistic operational testing and evaluation primarily contingent on satisfaction of the system operational reliability requirement or other supportable justification (e.g., combination of proximate reliability estimate, well-understood failure modes, and tenable design improvements).

Reliability Growth Methodologies. Currently, every developmental system is required to establish an initial reliability growth curve and to revise the curve as needed when program milestones are achieved or in response to unanticipated testing outcomes. The current strategy is to bring the system’s operational reliability at the end of developmental testing to a satisfactory point, thus supporting stand-alone operational testing and evaluation, with acceptable statistical performance characteristics. This strategy is eminently reasonable.

Reliability growth models can be used to synthesize data from different tests and to track and project progress towards attaining intermediate and final reliability target values. However, care must be taken to ensure that underlying model assumptions are not violated.

Developer’s Reliability Management. The execution of a developer’s reliability testing program should be overseen and governed by a formal reliability management structure that is empowered to make reliability an acquisition priority, retains flexibility to respond to emerging results, and comprehensively archives hardware and software reliability test designs, data, and assessments. Complete documentation should be budgeted for and made available to all relevant program and DoD entities.

DoD Oversight Processes. DoD oversight spans the complete spectrum of acquisition activities, beginning with the formulation of reliability requirements. The processes for designing and developing a reliable system should draw on pertinent previous program histories and incorporate contributions from user and testing communities. Implementations should be reviewed and supplemented, as needed, by external subject-matter experts with relevant reliability engineering and technical proficiencies.

For software-intensive systems and subsystems, a contractor’s development of the software architecture, specifications, and oversight management plan needs to be reviewed independently by DoD and external subject-matter experts. Automated

software testing tools and supporting documentation should be developed and reviewed by an outside panel of subject-matter experts appointed by DoD.

Exhibited reliabilities should be monitored and tracked to gauge progress towards achieving formal operational reliability requirements. Of critical importance is the scored reliability at the beginning of system-level testing, a direct reflection of the quality of the system design and production processes. If by the end of operational testing the attainment of adequate system operational reliability has not been demonstrated with satisfactory confidence, DoD should not approve the system for full-rate production and fielding without a formal review of the likely effects that deficient reliability would have on mission success and system life-cycle costs.

Feedback Mechanisms. DoD should encourage the establishment of information-sharing repositories that document individual reliability program histories and are made available to support future system acquisitions. Documentation should include demonstrated reliability results and underlying conditions from developmental testing, operational testing, and post-deployment operation. In developing and using this database, DoD needs to ensure that the data are fully protected against the disclosure of proprietary and classified information.

FUNDING AND RESOURCES

Planning for and conducting a robust testing program for increasing system reliability requires that sufficient funds be allocated for design, testing, and oversight activities and that the funding be dedicated so that it cannot be redirected for other purposes. Early investments in reliability are typically more than regained in the form of reduced life-cycle costs. Decisions about proposals, awarding contracts, and performance incentives for contractors all should consider long-term program costs.

To perform at a level consistent with best industrial practices, DoD needs to develop and maintain expertise in a number of domains—reliability engineering, software reliability engineering, reliability modeling, accelerated testing, and the reliability of electronic components—through combinations of in-house hiring, consulting or contractual agreements, and the training of current personnel.

PANEL ON THE THEORY AND APPLICATION OF RELIABILITY GROWTH MODELING TO DEFENSE SYSTEMS

ARTHUR FRIES (Chair), Institute for Defense Analyses, **W. PETER CHERRY**, Chief Analyst, Science Applications International Corporation, **ROBERT G. EASTERLING**, Statistical Consultant, **ELSAIED A. ELSAYED**, Rutgers University, Department of Industrial and Systems Engineering, **APARNA V. HUZURBAZAR**, Los Alamos National Laboratory, Statistical Sciences Group, **PATRICIA A. JACOBS**, Naval Postgraduate School, Operations Research Department, **WILLIAM Q. MEEKER, JR.**, Iowa State University, Department of Statistics, **NACHI NAGAPPAN**, Microsoft Research, Empirical Software Engineering Group, **MICHAEL PECHT**, University of Maryland, Clark School of Engineering, **ANANDA SEN**, University of Michigan, Department of Family Medicine, **SCOTT VANDER WIEL**, Los Alamos National Laboratories, Statistical Sciences Group; **CONSTANCE F. CITRO**, Director, Committee on National Statistics; **MICHAEL L. COHEN**, Study Director; **MICHAEL J. SIRI**, Program Associate.

For More Information . . . This brief was prepared by the Committee on National Statistics (CNSTAT) based on the report *Reliability Growth: Enhancing Defense System Reliability* (2015). The study was sponsored by the U.S. Department of Defense via the National Science Foundation. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect those of the sponsors. Copies of the report are available from the National Academies Press; (800) 624-6242; <http://www.nap.edu> or via the CNSTAT web page at <http://www.nationalacademies.org/cnstat>.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The nation turns to the National Academies—National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council—for independent, objective advice on issues that affect people's lives worldwide.

www.national-academies.org

Copyright © 2015 by the National Academy of Sciences.

Permission is granted to reproduce this document in its entirety, with no additions or alteration.