Summary of Findings and Recommendations From the National Research Council Report on *Reliability Growth: Enhancing Defense System Reliability*

http://www.nap.edu/catalog/18987/reliability-growth-enhancing-defense-system-reliability

Arthur Fries

Conference on Applied Statistics in Defense

21 October 2015

~~Overview of~~

Summary of Findings and Recommendations From the National Research Council Report on *Reliability Growth: Enhancing Defense System Reliability*

~~Mike Cohen~~ Arthur Fries

~~Committee on National Statistics~~

~~NDIA Conference March 3, 2015~~

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NRC Reports Related to DoD T&E
(excluding Interim reports)

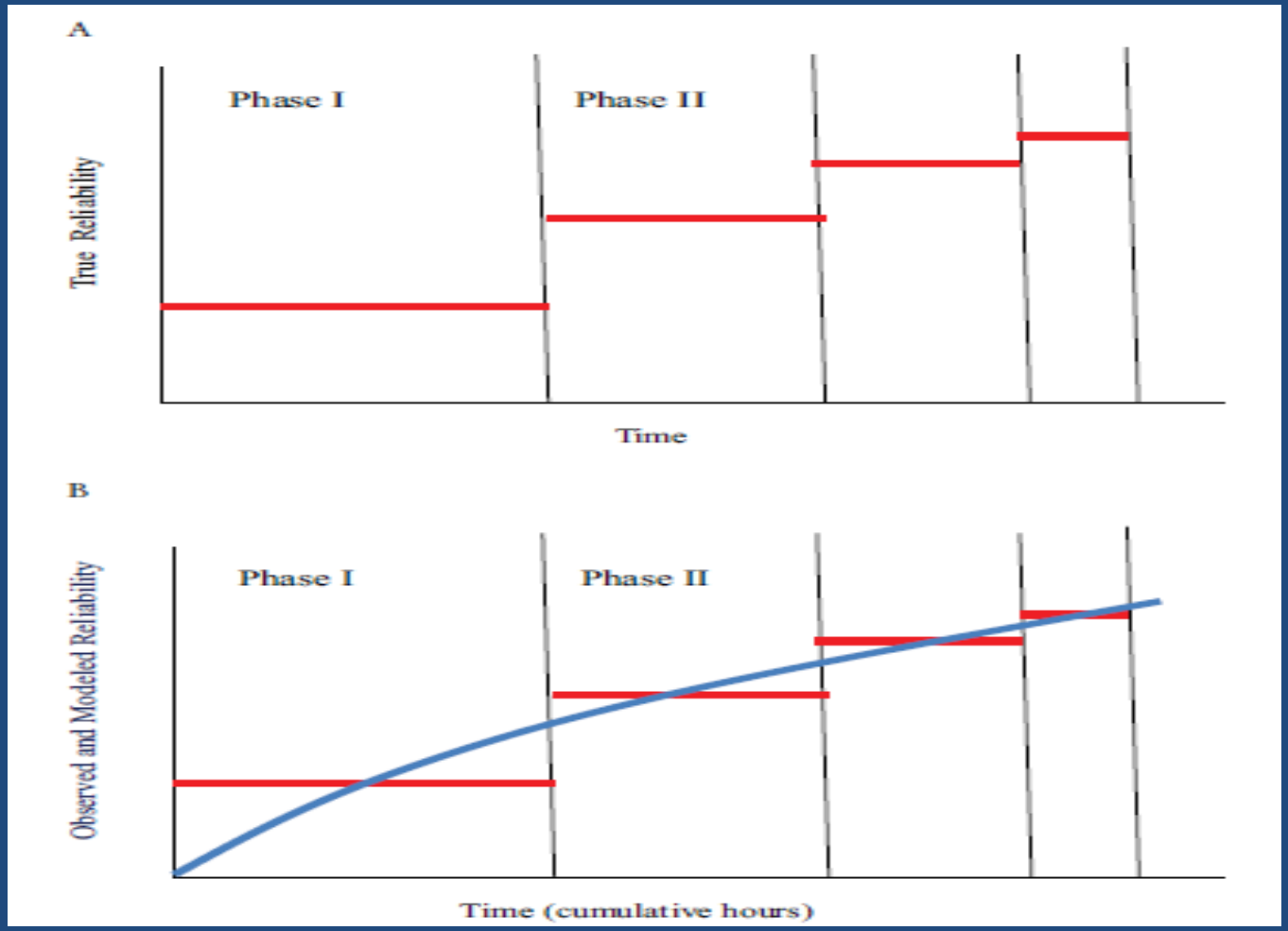
- Committee on National Statistics reports:
  - Rolph, J. E. and Steffey, D. L., eds. (1994), *Statistical Issues in Defense Analysis and Testing: Summary of a Workshop*, Washington, DC: National Academy Press. (Sponsors: DOT&E AND PA&E)
  - Cohen, Michael L., John E. Rolph, and Duane L. Steffey, eds. (1998), *Statistics, Testing, and Defense Acquisition: New Approaches and Methodological Improvements*, National Academy Press. (Sponsor: DOT&E)
  - National Research Council (2002), *Reliability Issues for DoD Systems: Report of a Workshop*, National Academies Press. (Sponsors: DOT&E and AT&L)
  - Siddhartha R. Dalal, Jesse H. Poore, and Michael L. Cohen, eds. (2003) *Innovations in Software Engineering for Defense Systems*, National Academies Press. (Sponsor: DOT&E and AT&L)
  - National Research Council (2004), *Improved Operational Testing and Evaluation and Methods of Combining Test Information for the Stryker Family of Vehicles and Related Army Systems: Phase II Report*, National Academies Press. (Sponsor: ATEC)
  - Vijay Nair and Michael L. Cohen, eds. (2006), *Testing of Defense Systems in an Evolutionary Acquisition Environment*, National Academy Press. (Sponsors: DOT&E and AT&L)
  - National Research Council (2012), *Industrial Methods for the Effective Development and Testing of Defense Systems*, National Academy Press. (Sponsors: DOT&E and AT&L)
  - **National Research Council (2015), *Reliability Growth: Enhancing Defense System Reliability*, National Academy Press. (Sponsors: DOT&E and AT&L)**

- Board on Army Science and Technology reports:
  - National Research Council (2012), Testing of Body Armor Materials: Phase III, National Academy Press. (Sponsor: DOT&E)
  - National Research Council (2014), Review of Department of Defense Test Protocols for Combat Helmets. (Sponsor: DOT&E)

Why "Reliability Growth" Topic?

- Between 1985 and 2011, depending on the years of interest, large fractions (25-60%) of DoD developmental systems failed to meet operational reliabiliy requirements
  - Leads to program delays and expensive redesigns
  - Impacts operational mission performance
  - Drives up lifetime maintenance and sustainability costs
- DoD recently instituted handbooks, guidance, and formal memoranda aimed at enhancing reliability practices and attained system reliabilities
  - Reliability growth model mandated to appear in system Test and Evaluation Master Plan
  - Reliability growth models popular for data aggregation across test phases

Reliability Growth Illustrations



Panel Charge

- Initial
  - The Committee on National Statistics initially received funding from DOT&E and AT&L to look into reliability growth models, what they are and are not useful for, and how they can be improved. Nice, focused study.
- Revised
  - At the first meeting it was decided to expand the charge to include reliability growth more generally, i.e., how to grow reliability – to look into design for reliability, reliability testing, and also the administration of reliability growth, including the development of requirements, the content of RFPs and proposals, and the communication between contractors and DoD and other oversight issues.

Panel Roster

Panel Members

- Arthur Fries (chair), IDA
- Peter Cherry, SAIC (retired)
- Rob Easterling, Sandia (retired)
- Elsayed Elsayed, Rutgers
- Aparna Huzurbazar, Los Alamos
- Pat Jacobs, NPGS
- Bill Meeker, Iowa State University
- Nachi Nagappan, Microsoft Research
- Michael Pecht, University of Maryland
- Ananda Sen, University of Michigan
- Scott Vander Wiel, Los Alamos

Other

- Ernest Seglie, DOT&E (retired) unpaid consultant
- Mike Cohen, CNSTAT - study director

What We Did

1. First, we had the initial meeting at which the charge was revised.

2. Then we had a large workshop:

Speakers:

- Frank Kendall, AT&L
- Michael Gilmore, DOT&E
- Andy Monje, OSD
- David Nicholls, RIAC
- Paul Shedlock, Raytheon
- Tom Wissink, Lockheed Martin
- Lou Gullo, Raytheon
- Guangbin Yang, Ford
- Shirish Kher, Alcatel-Lucent

What We Did (continued)

More Workshop Speakers:

- Martha Gardner, General Electric
- Mike Cushing, AEC (retired)
- Bud Boulter and others from AFOTEC
- James Woodford, US Navy
- Karen Bain, NAVAIR
- William McCarthy, OPTEVOR
- Patrick Sul, DOT&E
- Paul Ellner, ATEC
- Nozer Singpurwalla, George Washington University
- Don Gaver, NPGS
- Steve Brown, Lennox International

3. Finished with 3 panel meetings in executive session.

What We Found/Recommended

- Alternative Summaries
  - Findings and Recommendations Overview
  - Chapter Overviews
  - Recommendations
- Scope
  - Aimed at improving 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.
  - Some 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.
  - Comprise 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.

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.

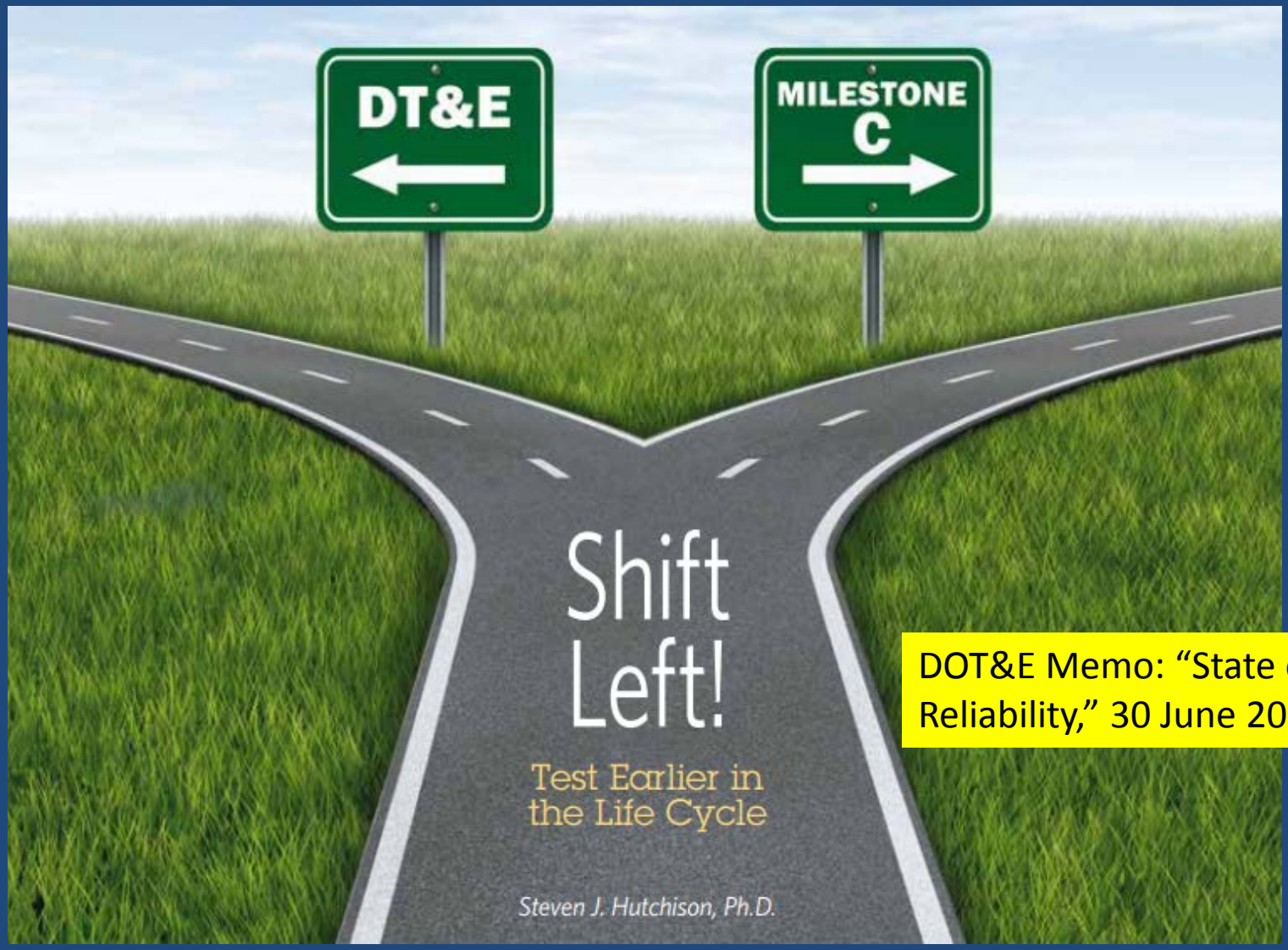
Findings and Recommendations: Overview (continued)

- 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 postdeployment performance to inform current and future developmental programs.

Findings and Recommendations: Overview (continued)

- 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.

“Shift to the Left”



DOT&E Memo: “State of Reliability,” 30 June 2010

Source: http://www.dau.mil/publications/DefenseATL/DATLFiles/Sep-Oct2013/Hutchison.pdf

Structure of Report

- Summary
- Chapter 1 – Charge
- Chapter 2 – Perspective from Industry
- Chapter 3 – Reliability Metrics
- Chapter 4 – Reliability Growth Modeling
- Chapter 5 – Design for Reliability
- Chapter 6 – Reliability Testing
- Chapter 7 – Developmental Test and Evaluation
- Chapter 8 – Operational Test and Evaluation
- Chapter 9 – Software Reliability Growth
- Chapter 10 – Conclusions and Recommendations
- Appendices – Recommendations in related reports, Workshop agenda, Recent history, MIL HDBK 217, Bios

Chapter Overviews

Summary: Main themes followed by all 25 recommendations

Chapter 1: Nature of the problem, the charge, recent history, some terminology, defense acquisition, report structure.

Chapter 2: Differences between defense acquisition and what goes on in the commercial sector, discussion of incentives, commercial best practices.

Chapter Overviews (continued)

Chapter 3: Reliability Metrics. Continuously operating repairable, ditto nonrepairable, and one-shot systems, MTBOMF and other simple statistics can be fine, but important to check assumptions, does repair bring system back to as good as new or as good as old, Poisson process is over-used, reliability is a function of the environment, so metrics need to keep that in mind.

Chapter 4: (Hardware) Reliability Growth Models. Used for planning, tracking, and predicting. Often not a function of environment, just a function of time on test. Good for planning and tracking, not so good for predicting. Need to assess assumptions. E.g., steady improvement is unlikely when adding new capabilities or joining subsystems. Some new ideas might be useful.

Chapter Overviews (continued)

Chapter 5: System Design for Reliability. Not just adding redundancy. Selection of parts, materials, worrying about interfaces, etc. FMMEA. Temperature, humidity, vibration, atmospheric contaminants, electromagnetic radiation, sand and dust, etc.

Chapter 6: Reliability Growth through Testing. Mainly highly accelerated life testing, accelerated life testing, and accelerated degradation testing. There are non-trivial design issues that arise.

Chapter Overviews (continued)

Chapter 7: DT&E. Communication between contractor and DoD. DT should be a continuation of contractor testing. Designed experiments important. Data analysis should be more disaggregate than simply estimating the summary measures for promotion. Merging data across test events not easy. Reliability growth monitoring raises some complications. Both target and observed metrics have variability. Deciding on promotion to OT.

Chapter 8: OT&E. Role of OT. Too late to find things to deal with them efficiency, including reliability problems. So don't want to find much wrong reliability-wise. Again test design, and test data analysis. DT/OT gap.

Chapter Overviews (continued)

Chapter 9: Software reliability growth models, performance metrics and prediction models, metrics-based models, building metrics-based prediction models, testing, monitoring.

Chapter 10: Conclusions and Recommendations

Recommendations (1-4)

- # 1: Analysis of alternatives should include an assessment of relationship between system reliability and mission success, and between system reliability and life-cycle costs.
- # 2: Need for a technical report justifying reliability requirements, including the linkage between reliability and life-cycle costs, and feasibility, measurability, and testability, and this should be reviewed by a panel of experts.
- # 3: Any proposed changes to reliability requirements should be approved by at least the service component acquisition authority. Part of consideration should be impact on mission success and life-cycle costs.
- # 4: Need for an outline reliability demonstration plan to be included in RFP that shows how system will be tested by DoD and how it's reliability is expected to improve. This should also be reviewed by a panel of experts prior to use in an RFP.

Recommendations (5-8)

- # 5: Reliability should be a key performance parameter.
- # 6: All proposals should specify the design for reliability techniques that the contractor will use during system design. There should be a line item for the costs of DFR techniques.
- # 7: All proposals should include an initial plan for system reliability and qualification as well as a description of the reliability organization and reporting structure. This should be regularly updated – an up-to-date assessment of what is known by the contractor about hardware and software reliability at the component , subsystem, and system level.
- # 8: System developers should use modern DFR techniques, particularly physics of failure methods, to support system design and reliability estimation. MIL-HDBK-217 and its progeny have grave deficiencies.

Recommendations (9-12)

- # 9: For software systems and subsystems, all proposals should specify a management plan for software development and that the contractor will provide DoD will full access to system architecture, metrics being tracked, and archived log of the management of system development. (failure reports, time of incidence, time of fix)
- # 10: Validity of assumptions underlying application of reliability growth models should be carefully assessed. Reliability growth models should not be used to forecast substantially into the future. Exception – early in system development
- # 11: Contractors should specify an initial reliability growth plan and the outline of a testing program to support it, recognizing that they are preliminary. Cost, level of test, size, schedule, etc.
- # 12: Contractors should archive and deliver to DoD all data from reliability testing and other related analyses. Also include all failure reports, times of failure, and times of resolution.

Recommendations 13-16

- # 13: Expert panels to review designs of accelerated test plans, and models linking accelerated to typical use.
- # 14: For all software systems and subsystems, DoD should mandate that the contractor provide DoD with access to automated software testing capabilities to enable DoD to conduct its own automated testing.
- # 15: DoD should mandate the assessment of the impact of any major changes to system design on the existing plan for DFR and reliability testing.
- # 16: DoD should mandate that contractors specify to their subcontractors the range of anticipated environmental load conditions that the system needs to withstand.

Recommendations 17-20

- **# 17: DoD should ensure that there is a line item in all acquisition budgets for oversight of subcontractors compliance with reliability requirements.**
- **# 18: DoD should mandate that proposals include appropriate funding for DFR and testing in support of reliability growth and that awarding of contracts will take that into consideration. Changes after award require approval at a high level.**
- **# 19: Prior to delivery of prototypes to DoD for DT, the contractor must provide test data supporting a statistically valid estimate of system reliability consistent with the operational reliability requirement.**
- **# 20: Near end of DT, there should be full-system, operationally relevant test during which the reliability performance of the system will equal or exceed required levels. Needed to go forward.**

Recommendations 21-25

- **# 21: DoD should not pass a system that has deficient reliability to the field without a formal review of the resulting impacts on mission success and life-cycle costs.**
- **# 22: Collect post-deployment reliability data for all fielded systems to support various feedback loops.**
- **# 23: After a system is in production, changes in suppliers or manufacturing or assembly, storage, etc. needs review that it will not affect system reliability.**
- **# 24: DoD should create a database with (1) outputs – reliabilities at various stages of development, (2) inputs – variables that describe the system and the testing conditions, and (3) system development processes used to support analysis. Also for major subsystems.**
- **# 25: DoD needs additional technical expertise in: (a) reliability engineering, (b) software reliability engineering, (c) reliability modeling, (d) accelerated testing, and (e) the reliability of electronic components.**

Report Impact?

- Sponsors happy!
- DoD processes?
- Individual program reliabilities?