Studies and Methods for Improving the Effectiveness of Reliability Tasks

Larry H. Crow, Ph.D., Crow Reliability Resources

Key Words: Reliability tasks, Reliability growth, Effectiveness metrics, Initial MTBF, Growth potential

SUMMARY & CONCLUSIONS

The main Department of Defense (DoD) document on reliability tasks from 1980 until it was rescinded by DoD in the early 1990's was Mil Std 785, Reliability Program for Systems and Equipment, Development and Production (Ref. 1). Although this document has been rescinded by DoD, it is still widely used for establishing the tasks of a reliability program. Other related documents with similar tasks are IEC International Standards, ANSI National Standards, and various industry handbooks and standards. These documents have many typical reliability management and analysis tasks in common such as prediction, allocation, worst case analyses, part selection, Failure Mode Effects and Criticality Analysis (FMECA), Failure Reporting and Corrective Action System (FRACAS), etc.

DoD studies have shown that even when the basic reliability tasks are implemented the resulting system reliability is often lower than expected and often insufficient. This problem was addressed by the Panel on Statistical Methods for Testing and Evaluating Defense Systems, National Research Council (NRC) in 1998 (Ref. 2). In order to gain additional information, two DoD agencies—the Office of the Director of Operational Test and Evaluation and the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics—asked the NRC's Committee on National Statistics to initiate a series of workshops on statistical issues relevant to defense acquisition. The aim of each workshop was to inform DoD about the methods that represent the statistical state of the art and, through interactions of the statistical and defense communities, explore their relevance for DoD application.

One of the workshop's recommendations (See Ref. 3) was to upgrade, or replace, DoD 3235.1-H, Test and Evaluation of System Reliability Availability and Maintainability: A Primer, (Ref. 4), with a publication that provides a more modern coverage of the relevant issues. The workshop stressed that a change in emphasis is needed, including a greater focus on test and evaluation for suitability, but more important, use of a number of techniques that can help identify design flaws and provide assessments of reliability performance much earlier in system development. The rewrite of the Primer DoD 3235.1-H is currently in progress.

Significant to the NRC's recommendations to DoD and the rewrite of the Primer is the question: Just how effective are reliability tasks in identifying design flaws and correcting reliability deficiencies early in system development? Clearly the effectiveness will vary from system to system but are there data or studies that will give us insight into this issue? The focus of this paper is to provide a framework and data for addressing these questions. In particular, this paper defines a practical metric to measure the effectiveness of the reliability tasks that take place before reliability growth or other prototype testing. We will then use data from Department of Army and Bell Laboratories studies to calculate this metric for the systems discussed. In addition the paper will provide a number of proven methods for increasing the effectiveness of several reliability tasks.

1. INTRODUCTION

When a new, complex system is developed, reliability is often a key consideration. The reasons for this interest may vary but often include the following objectives: 1) maintaining a level of functionality without a critical failure for a desired period of time 2) reducing cost to maintain and support the system 3) managing safety issues due to the consequence of a failure. As an effort to attain these objectives, reliability requirements or goals are generally established and a reliability program instituted where various reliability tasks are performed during system development. As presented in Mil Std 785 these tasks are categorized into three main areas; Program Surveillance and Control (or Management), Design and Evaluation, and Development and Production Testing. The Program Surveillance and Control and the Design and Evaluation tasks are basically conducted prior to full prototype builds. The Development and Production Testing tasks are conducted utilizing the prototypes which are a result of the Program Surveillance and Control and the Design and Evaluation tasks.

For a particular program, an important factor in whether or not these tasks yield the desired reliability is the management strategy. Management strategy may be driven by budget but it is defined by the actual actions of management in correcting reliability problems. If the reliability of a failure mode is known through analysis or testing, then the management strategy makes a decision to either not to fix (no corrective action) or to fix (implement a corrective action) for that failure mode. Generally, if the reliability of the failure mode meets the expectations of management, then no corrective actions would be expected. If the reliability of the failure mode is below expectations, the management strategy would generally implement a corrective action. Another part

0-7803-8824-0/05/$20.00 (C) 2005 IEEE

of the management strategy is the effectiveness of the corrective actions. A corrective action typically does not eliminate a failure mode from ever recurring again. It simply reduces its rate of occurrence. A corrective action, or fix, for a problem failure mode typically removes a certain amount of the failure mode's failure rate, but a certain amount will remain in the system. The fraction decrease in the problem mode failure rate due to the corrective action is called the Effectiveness Factor (EF). The EF will vary from failure mode to failure mode but a typical average for DoD and industry systems is about .70. See Ref. 5. That is, on average a corrective action removes about 70% of the failure rate, but 30% remains in the system.

If through analysis or testing all problem failure modes were identified for management to act in accordance with the management strategy then the resulting reliability is the Growth Potential. This is the maximum reliability attainable with the design and management strategy. In order to reach the requirement or goal, these objectives must be below the Growth Potential. Different management strategies may yield different Growth Potentials for the same engineering design. One management strategy may fix a large number of problems if they are uncovered and another management strategy may only fix a few problems.

Reliability problems for management to act on may be found during early design and during any later reliability testing. If there is no significant follow on reliability testing all meaningful uncovering of reliability problems will occur during the design phase. In this case the actual reliability attained will depend on the Growth Potential (design and management strategy) and the ability of the reliability tasks that are conducted to uncovered and correct problems.

Section 2 will develop the framework to define a meaningful metric for measuring the effectiveness of reliability tasks in terms of identifying reliability design flaws and correcting these deficiencies early in system development. We call this metric the Basic Reliability Tasks Effectiveness (BRTE). We then use existing studies to derive information to calculate this metric for actual systems. Methods will then be discussed to help increase this BRTE metric on a program.

Notation

GP	Growth Potential
EF	Effectiveness Factor
BRTE	Basic Reliability Tasks Effectiveness
IRGT	Integrated Reliability Growth Test

2. BACKGROUND

To lay the groundwork for the main results of this paper, we will first discuss the reliability tasks conducted in most of the systems in the studies. This will also be useful in establishing the BRTE metric framework for addressing the effectiveness of the tasks.

2.1. Background on Reliability Tasks

We cite Mil Std 785 as a reference of the reliability tasks, as it is widely used and readily available. In addition, the studies discussed later are based on reliability data generated from systems in which Mil Std 785 tasks, or similar tasks, were invoked in establishing the reliability programs.

The Mil Std 785 Program Surveillance and Control tasks include:

101 Reliability Program Plan
102 Monitor/Control of Subcontractors and Suppliers
103 Program Reviews
104 Failure Reporting, Analysis, and Corrective Action System (FRACAS)
105 Failure Review Board (FRB)

The Mil Std 785 Design and Evaluation tasks include:

201 Reliability Modeling
202 Reliability Allocations
203 Reliability Predictions
204 Failure Modes, Effects, and Criticality Analysis (FMECA)
205 Sneak Circuit Analysis
206 Electronic Parts/Circuit Tolerance Analysis
207 Parts Program
208 Reliability Critical Items
209 Effects of Functional Testing, Storage, Handling, Packaging, Transportation, and Maintenance

In this paper we grouped the Program Surveillance and Control and Design and Evaluation tasks into a group called "Basic Reliability Tasks." These are basic tasks in the sense that many of these tasks are included in a comprehensive reliability program.

The Mil Std 785 Development and Production Testing tasks include:

301 Environmental Stress Screening (ESS)
302 Reliability Development/Growth Test (RDGT)
303 Reliability Qualification Test (RGT) Program
304 Production Reliability Acceptance Test (PRAT) Program.

Of these Mil Std 785 300 series tasks, only the RDGT testing task is specially directed toward finding and correcting reliability deficiencies.

2.2 Reliability Parameter

This paper considers the reliability metric of interest to be Mean Time Between Failures (MTBF). This term is used for continuous systems as well as "one shot" systems. For one shot systems this metric is the mean trial or shot between failures and is equal to 1/failure probability.

3. KEY RELIABILITY TASKS PARAMETERS

The MTBF of the prototypes immediately after the Basic Reliability Tasks are completed is called the Initial MTBF. This is a key Basic Reliability Tasks output parameter. If the system is tested after the completion of the Basic Reliability Tasks then the Initial MTBF is the mean time between failures as demonstrated from actual data. The Initial MTBF is the reliability actually achieved by the Basic Reliability Tasks and is the system MTBF if the reliability program were stopped after the Basic Reliability Tasks are completed. If the Initial MTBF is less than the Growth Potential MTBF this means that not all problem failure modes were uncovered during the Basic Reliability Tasks for management to act on in accordance with the management strategy. The Initial MTBF is a key Basic Reliability Tasks output parameter.

If the system is subjected to RDGT the Initial MTBF is the system reliability at the beginning of the test. RDGT is conducted after the Basic Reliability Tasks have been completed. At the beginning of RDGT, the Initial MTBF is lower than desired in terms of management expectations and goals. RDGT testing is conducted and failures observed. When a new failure mode is observed during testing, management makes a decision to either not correct (called Type A modes) or correct (called Type B modes) the failure mode in accordance with the management strategy. If the EF is greater than 0 for a Type B mode, the failure rate for the failure mode is decreased. If the RDGT testing is sufficient, the system MTBF will grow to a mature MTBF value in which further corrective actions are very infrequent. This mature MTBF value is the Growth Potential. Consistent with previous discussion in this paper this mature RDGT MTBF value is the system Growth Potential MTBF that would be attained at the end of the Basic Reliability Tasks if all the problem failure modes were uncovered to management in early design and corrected in accordance with the management strategy.

Because the system design is determined during the Basic Reliability Tasks, the Growth Potential is also a key Basic Reliability Tasks output parameter. The Initial MTBF is the value actually achieved by the Basic Reliability Tasks. The Growth Potential is the reliability that can be attained. See Fig. 1.

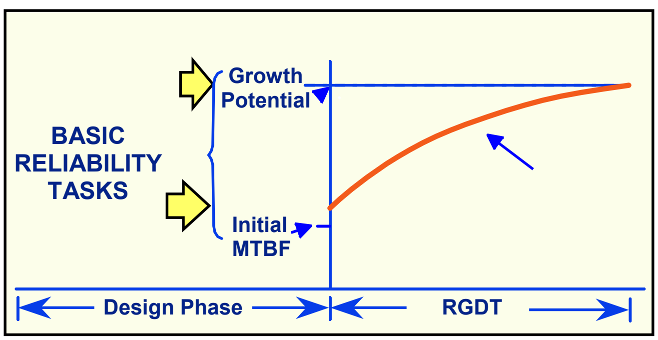

Figure 1. Key Basic Reliability Tasks Output Parameters

If a system is subjected to RDGT, the reliability at the end of this test is called the Final MTBF. If the MTBF is matured, the Growth Potential MTBF equals the Final MTBF. Therefore, for systems matured during RDGT, we can measure the Growth Potential MTBF. With proper data we can also measure the Initial MTBF at the beginning of RDGT. With this framework data from RDGT can be used to measure the two key Basic Reliability Task parameters.

4. *BASIC RELIABILITY TASKS EFFECTIVENESS*

In this paper we consider the Basic Reliability Tasks Effectiveness (BRTE) metric as the ratio:

BRTE= Initial MTBF/ Growth Potential MTBF.

This is the ratio of the reliability actually achieved by the Basic Reliability Tasks to the reliability that is attainable, the Growth Potential.

If the basic tasks were 100% effectiveness, the Initial MTBF would equal the Growth Potential. The objective of the paper is to utilize study results on RDGT to gain insight on the BRTE. For example, suppose the Initial MTBF at the beginning of RDGT was 100 and the Final MTBF is 400. In this illustration, the Initial MTBF output of the Basic Reliability Tasks is 100. If the MTBF is matured at 400 by RDGT, the Growth Potential MTBF output of the Basic Reliability Tasks is 400. This means that these tasks achieved 25 % of the Growth Potential. That is, the effectiveness of the Basic Reliability Tasks was 25 % or BRTE = .25.

5. BRTE Study Results

In this section we will present BRTE results from three studies in which we calculated the effectiveness based on reliability growth data. Some systems in these studies were developed during the late 1970s but most were developed during the 1980s. The systems had comprehensive reliability programs including reliability growth testing. This information is relevant to current systems because many of the Basic Reliability Tasks are standard activities and the general approach for implementation has changed very little.

5.1. Helicopter Study

This study was conducted by the author in the early 1980s and consisted of reconstructing the reliability growth profile for a helicopter developed by the Army. Basic Reliability Tasks were performed on the helicopter. After these tasks were completed a contractor reliability growth test was conducted. The system was then subjected to a formal reliability growth program conducted by the U.S. Army. The helicopter reliability growth profile, beginning with the early contractor prototype testing and continuing through initial production is given in Figure 2.

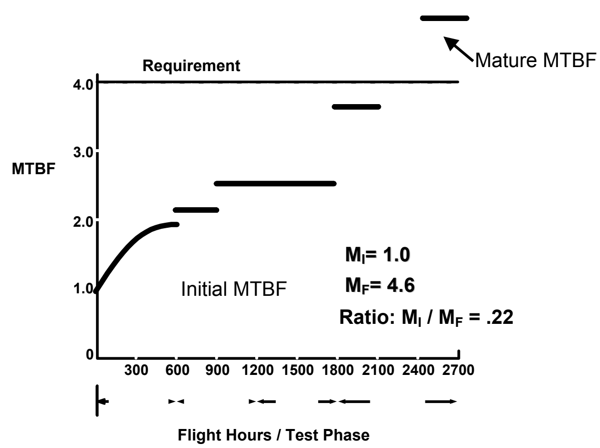

Figure 2. Helicopter Reliability History

The initial MTBF (for unscheduled maintenance actions) was 1.0 hour. The requirement was 4.0 hours. The Final MTBF attained was 4.6 hours. Because the final MTBF represents a mature system, the Final MTBF equals the Growth Potential. The two key Basic Reliability Tasks output parameters are:

- The Initial MTBF =1.0 hour
- The Growth Potential MTBF = 4.6 hours.

Therefore the effectiveness of the helicopter Basic Reliability Tasks metric is: BRTE = 1.0/4.6 = 0.22.

5.2. Department of Army Reliability Growth Study

This study, entitled "AMSAA Reliability Growth Data Study", Ref. 5, was conducted by the Department of Army and completed in 1990. This report presented results on the growth rates, ratios of the Initial MTBF to the mature Final MTBF, and fix effectiveness factors on major Army systems. Systems studied included missiles, mechanical/electronic equipment, and electronic equipment. The helicopter discussed in Section 5.1 was included in this set. However, in the AMSAA study the start of the test data utilized was later than the data in Section 5.1. The data in Section 5.1 is immediately after the completion of the Basic Reliability Tasks and gives an Initial MTBF that is more appropriate for calculating the BRTE as defined in this paper.

In addition to the helicopter there were nine systems analyzed by AMSAA. These included six missiles, one mechanical/electronic system, and two electronic systems. All of these reliability programs had the Basic Reliability Tasks and a comprehensive reliability growth testing program in which the reliability was matured by corrective actions.

The missile BRTE results are given in Table 1. The mechanical/electronic system BRTE is given in Table 2. The electronics systems BRTE are given in Table 3.

System	BRTE
Missile 1	0.17
Missile 2	0.15
Missile 3	0.31
Missile 4	0.32
Missile 5	0.47
Missile 6	0.18
Average	0.27

Table 1. Missile BRTE Metrics

System	BRTE
M/E System	0.31
Average	0.31

Table 2. Mechanical/Electronic Systems BRTEMetrics

System	BRTE
E System 1	0.34
E System 2	0.34
Average	0.34

Table 3. Electronic Systems BRTE Metrics

For the systems in the three tables the average BRTE metric is 0.29.

5.3. Industry Study

This study involved an electronic system at AT&T Bell Labs that was subjected to extensive dedicated reliability testing after the completion of the Basic Reliability Tasks. This testing uncovered eleven reliability failure modes. Eleven corrective actions were identified and all eleven corrective actions were introduced at the same time. The system was again subjected to extensive testing to verify the corrective actions and assure the design was mature. From this testing excellent estimates of the system and each failure mode's reliability before and after the corrective actions were estimated. From this information, given in Ref. 6, we can calculate the BRTE. See Fig. 3.

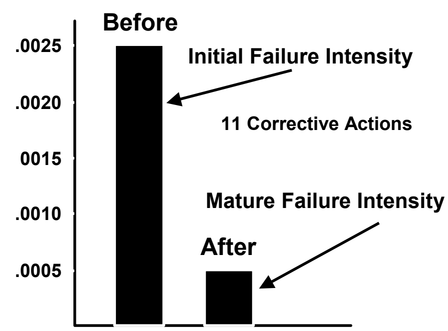

Figure 3. Bell Labs Electronic System Data

For this system the BRTE = (.0005/.0025) = 0.20.

6. IMPLICATIONS FOR A RELIABILITY PROGRAM

If the reliability requirements are low relative to the Growth Potential, having a low BRTE may not present a problem. However, reliability requirements are usually set high, such that the Initial MTBF may not be adequate. The actual Initial MTBF will clearly vary for program to program and the previous studies highlight the fact that even when extensive reliability effort and resources are expended, the Initial MTBF may be lower than the capability of the design. This is why the workshop stressed that a change in emphasis of a reliability program is needed to help identify design flaws much earlier in system development.

Within the framework given in this paper, uncovering and fixing more problems in early design is consistent with increasing the Initial MTBF, or equivalently, the BRTE. Under the modern reliability management approach the Initial MTBF is a key metric to be managed in addition to the Growth Potential. In the next section several proven approaches to increase the Initial MTBF are given.

7. METHODS FOR INCREASING THE INITIAL MTBF

In this section we discuss some proven methods for increasing the Initial MTBF. In all cases the recommendations consist of implementing the common reliability tasks in a different manner than is usual.

7.1 Failure Prevention and Review Board

Usually, potential reliability problems can be mitigated by the reliability engineer and product design team. Sometimes, however, a potential problem needs special management attention due to high risks, costs, criticality, additional screening or testing, or schedule impact. Without a focused approach, resolution may not occur, or may be time consuming and expensive. For these critical problems, a reliability mitigation process at the system engineer and program manager level can greatly decrease the time and cost of a solution. To increase the Initial MTBF, a potential reliability design flaw is identified (see Enhanced FMECA in Section 7.3.), documented, and assigned to the appropriate person for resolution similar to the way a failure is reported. However, in this case, the failure has not yet occurred. The process is most effective when managed by the program manager, system engineer, and the reliability manager in much the same way as Task 105 Failure Review Board (FRB) for failures. This strategy is to prevent the problem from occurring. In this respect the Task 105 objective expands to become a "Failure Prevention and Review Board (FPRB)." That is,

FPRB = FRB + Failure Prevention.

7.2 Integrated Reliability Growth Test (IRGT)

Often reliability problems are surfaced early in engineering tests. The focus of these tests is typically on performance and not reliability. Therefore, if the problem is not brought to the attention of reliability engineering it may not be corrected early in the design when corrective actions are the most cost effective and minimally impact schedules. Integrated Reliability Growth Test (IRGT) simply piggybacks reliability failure reporting on engineering tests. Task 104 Failure Reporting, Analysis, and Corrective Action System (FRACAS) is a management system and may or may not initiate failure analyses and corrective actions. However, if we use existing testing and add Failure Analysis and FPRB we have an effective IRGT. That is,

IRGT = FRACAS + Existing Testing + Failure Analysis + FPRB

7.2.1 Integrated Reliability Growth Test Study

In the previous studies the reliability growth testing was a concerted, dedicated effort to finding and correcting reliability problems. In this study (see Ref. 7) existing testing was used at AT&T Bell Labs during development to find reliability problems and take corrective actions. Reliability was not the primary objective of these tests. This is an integrated reliability growth test (IRGT) approach.

There were three systems in this study and the Crow (AMSAA) reliability growth model was fitted to the data for each system. Table 4 summarizes the approximate beginning and ending MTBFs, over the range of the integrated testing, based on the fitted growth models presented in Ref. 7.

	Beginning MTBF	Ending MTBF	Approx. Test Hours
System			
1	166	673	7500
2	298	759	9700
3	167	330	4100

Table 4. Summary of Bell Labs IRGT Data

This study illustrates examples of utilizing IRGT to supplement the Basic Reliability Tasks in order to increase the Initial MTBF. Under IRGT caution must be used in comparing the assessed reliability to requirements because of possible differences between prototypes and final product, test environment, etc.

7.3. Enhanced FMECA

Task 204 Failure Modes, Effects, and Critically Analysis (FMECA， is an analysis procedure which documents all probable failures in a system within specified ground rules, determines by failure mode analysis the effect of each failure on system operation, identifies single failure points, and ranks each failure according to a severity classification of failure effect.

The failure rates that are typically used for the FMECA are the same failure rates used in the prediction. Generally, predicted failure rates reflect a mature system design and do not reflect potential reliability problems in early development. Therefore, instead of a typical Task 204 FMECA, it is recommended that an enhanced FMECA be utilized where the risks areas associated with the design are noted. These areas are analyzed and potential problems are mitigated. As these problems are mitigated and reliability corrective actions taken in the design, the Initial MTBF will grow. Under the Enhanced FMECA approach the failure rate is not assumed to be the prediction for potential problem areas. Instead the approach is to assume the failure rate for a potential problem failure mode is suspect until it is investigated and properly mitigated. A Fault Tree Analysis (FTA) is a companion to the Enhanced FMECA and may be used to identify failure modes and causes. Some important risks areas are interaction failures. In Ref. 8 the authors note that "System interaction problems contribute heavily to warranty claims. This statistics vary considerably, but for automotive electronics it is not unusual to see more that 50% of unidentified warranty claims, often classified as CCNV (customer complaint not verified) or expressed in other similar terminology."

As an extension of Mil Std 785 Task 204 the

Enhanced FMECA = FMECA + FTA + Problem Identification + Mitigation Status.

REFERENCES

1. Mil Std 785, Reliability Programs for Systems and Equipment, Development and Production, National Technical Information Services, Springfield, Va.
2. National Research Council, Statistics, Testing, and Defense Acquisition: New Approaches and Methodological Improvements. Michael L. Cohen, John B. Rolph, and Duane L. Steffey, eds. 1998. National Academy Press.
3. National Research Council, Reliability Issues for DoD Systems, Report of a Workshop Francisco Samaniego and Michael Cohen , eds. 2002. National Academy Press.
4. Test and Evaluation of System Reliability, Availability, and Maintainability: A Primer. Report No. DoD 3235.1-H, third edition. 1982. U.S. Department of Defense. Washington, DC.
5. P. Ellner, B. Trapnell, AMSAA Reliability Growth Data Study, Interim Note R-18,.U. S. Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, Md. January 1990.
6. G. J. Gibson, L. H. Crow, Reliability Fix Effectiveness Estimation, Proceedings 1989 Annual Reliability and Maintainability Symposium, pp. 171-177, Atlanta, GA. January 1989.
7. J. Wronka, Tracking of Reliability in Early Development, Proceedings 1988 Annual Reliability and Maintainability Symposium, pp. 238-242, Los Angeles, CA
8. Kleyner, A., J. Boyle, The Myths of Reliability Demonstration Testing, Test Engineering & Management, Aug. / Sept. 04, pp. 16-17.

BIOGRAPHY

Larry H. Crow, Ph. D.
109 Clifts Cove Blvd.
Madison, AL 35758 U. S. A.

Internet (e-mail) Crowrel@knology.net

Dr. Larry H. Crow is president of CRR and provides services and resources in the areas of reliability consulting, training, and software development. Previously Dr. Crow was VP, Reliability& Sustainment Programs, at ALION Science and Technology, Huntsville, AL. From 1985 to 2000 Dr. Crow was Director, Reliability, at General Dynamics ATS- formally Bell Labs ATS. From 1971-1985, Dr. Crow was chief of the Reliability Methodology Office at the US Army Materiel Systems Analysis Activity (AMSAA). He developed the Crow (AMSAA) reliability growth model, which has been incorporated into US DoD handbooks, and national & international standards. He chaired the committee to develop Mil-Hdbk-189, *Reliability Growth Management* and is the principal author of that document. He is the principal author of the IEC International Standard 1164, *Reliability Growth-Statistical Tests and Estimation Methods*. Dr. Crow is a Fellow of the American Statistical Association, and the Institute of Environmental Sciences and Technology. He is a Florida State University Alumni Association Distinguished Alumnus and the recipient of the FSU "Grad Made Good" Award for the Year 2000, the highest honor given to a graduate by Florida State University.