Reliability Demonstration Testing: Can We Afford 80% Confidence?

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SUMMARY & CONCLUSIONS

The current Department of Defense (DoD) emphasis on improving the reliability of fielded systems by enhancing reliability-related activities during the acquisition process is clearly documented in Interim DoD Instruction (DoDI) 5000.02 [1], DoD Directive-Type Memorandum (DTM) 11-003 [2], and the Reliability, Availability, Maintainability, and Cost (RAM-C) Rationale Report Manual [3]. Program Managers are required to formulate a comprehensive and integrated Reliability and Maintainability (R&M) program using an appropriate strategy to ensure R&M requirements are achieved. Required activities include reliability testing at the system and subsystem level and inclusion of reliability growth curves in the program Systems Engineering Plan (SEP) beginning at Milestone A, and in the Test and Evaluation Master Plan (TEMP) beginning at Milestone B. This strong emphasis on RAM-C during acquisition is necessary and welcomed to ensure the warfighter's requirements are met. There are, however, challenges to be faced by program offices as they attempt to comply with these requirements, while cost effectively meeting the operational need.

Emphasis on accomplishment of reliability demonstration testing and reliability growth planning during new system acquisition has increased in recent years. While these activities provide an excellent opportunity to improve the fielded reliability of systems, challenges exist in balancing the risk of not achieving the required reliability with the cost of design, production, and reliability demonstration testing of systems.

In order to obtain the desired 80% confidence that a system meets the stated reliability requirement, a "Goal" value of Mean Time Between Failure (MTBF) (or whatever reliability metric defines the system requirement) must be established that is greater than the requirement. The exact value of the goal is dependent on the warfighter's requirement, planned demonstration test duration, and desired Producer and Consumer confidence levels. When these factors are all considered, the established Goal may become significantly higher than the warfighter requirement. This inflation of the requirement can lead to over-design of the system and a significant investment in reliability growth testing. This additional acquisition phase investment may not be cost-effective or justified unless sustainment phase cost can be significantly reduced over the service life of the system as a result of the improved reliability. However, a reduction in sustainment phase cost with a more "reliable" system is not always possible. For example, in the case where redundancy is added to a system to meet availability or mission reliability requirements, there is typically an increase in sustainment cost as a result of the additional complexity from the added equipment.

Extensive guidance and proven methodologies are currently available on reliability growth planning, but none adequately address the cost-benefit of achieving the inflated Goal. The return on investment associated with identifying and implementing design improvements and the increased test time associated with achieving 80% confidence in the system reliability should be an integral part of the decision making process throughout system acquisition and life cycle support activities.

1 BACKGROUND

Most system performance requirements can be demonstrated with high confidence through testing (such as weight or speed). However, since reliability is a probabilistic value it cannot be demonstrated by a simple (or short) test. We must resort to accepting some level of "confidence" that the requirement will be achieved based on limited testing. In a simplistic sense, this confidence is a function of the required reliability value, the number of failures experienced during the test, and test duration. While we know the requirement (from the system specification) and we can plan for realistic test duration, the number of failures experienced is a function of the "true" reliability of the system and, to some degree, random chance. In other words, we could be "lucky" and experience fewer failures during a test than the "true" reliability would predict or we could be "unlucky" and experience more failures than we would expect. Fundamentally, the longer the test duration, the less likely the results will be influenced by luck, but there are practical limitations on the test time. Since our test duration cannot be infinite, we are resigned to accepting some level of confidence less than 100%. A confidence value of 80% is generally accepted for demonstration of reliability requirements. The challenge is to demonstrate a reliability objective with 80% confidence. This often requires extending the test to allow collection of sufficient data to achieve confidence in the results.

The other major contributor to the required test duration (besides desired confidence levels) is the "true" or inherent system reliability. The more the true value exceeds the required value, the less test time is needed to provide 80%

confidence. This leads to establishing a “goal” or “design to” target reliability that may be as much as 50% to 100% greater than the required value in some cases. While it may seem like the best approach to reduce the risk of not demonstrating compliance with 80% confidence is to design above the requirement, in reality designing and producing a system that exceeds the required value adds significant development and production cost.

2 THE EFFECT OF 80% CONFIDENCE ON MTBF

The current programmatic method is to establish a Goal MTBF that is inflated above the warfighter requirement to ensure that the warfighter requirement can be demonstrated with statistical significance. This inflation takes into account the desired Producer and Consumer risks (i.e. 1 – Confidence), and the duration of the reliability demonstration testing [4]. Whereas this approach clearly reduces risk and improves the probability of passing the reliability demonstration test with the desired confidence, it can have unforeseen and undesired impact on program cost.

Let’s examine how the Goal MTBF is typically inflated in order to successfully demonstrate the requirement with 80% confidence in a limited duration test. Using the AMSAA PM2 Model’s [5] Operating Characteristics (OC) curve features, the Goal MTBF was determined for a couple of examples.

Based on the MTBF requirement, risk, and test duration parameters shown in the first example (Table 1), the Goal MTBF is 45% greater than the warfighter requirement. This Goal MTBF is the inflated “design-to” MTBF and represents the desired true MTBF of the system when it enters testing that will allow the required MTBF to be demonstrated during the planned test with the desired level of confidence.

Parameter	Value
Warfighter Requirement	100 hours
Producer Confidence	80%
Consumer Confidence	80%
Reliability Demonstration Test Duration	3,000 hours
Goal MTBF	145 hours
% Inflation of Requirement	45%

Table 1 – Goal MTBF Inflation - Example 1

When test duration is doubled as shown in Table 2, the Goal MTBF is significantly lower, but remains 28% greater than the warfighter requirement. The Goal MTBF is lower because the additional test duration provides a greater population of failures which provides greater confidence in the results.

Parameter	Value
Warfighter Requirement	100 hours
Producer Confidence	80%
Consumer Confidence	80%
Reliability Demonstration Test Duration	6,000 hours
Goal MTBF	128 hours
% Inflation of Requirement	28%

Table 2 – Goal MTBF Inflation - Example 2

There are obviously costs associated with designing to this inflated Goal MTBF that should be considered. Would the cost associated with overdesigning a system by this large of a margin for other common performance parameters (i.e. speed, range, accuracy, etc.) be acceptable to the program? That cost would likely be significant and the warfighter most likely would not be able to afford the resultant system.

3 THE COST OF 80% CONFIDENCE

System Life Cycle Cost (LCC) is the metric that should be considered when making design and programmatic decisions. As we know, LCC includes all acquisition, sustainment, and disposal cost. In reality however, the consideration of acquisition cost generally dominates early programmatic and design decisions in the interest of making sure programs can be funded with the limited budgets that are the current reality. Whereas reliability improvements (at least in basic reliability) have the opportunity to reduce sustainment cost over the life cycle (20 years or more), those savings are typically in discounted dollars and are generally not considered during acquisition phase programmatic decisions. The focus of decision makers is typically on the design, testing, production, and fielding cost incurred during the acquisition phase. For simplicity this discussion focuses on reliability program impacts to acquisition cost, although it is recognized that the methodology discussed here can and should be expanded to consider the potential sustainment phase cost saving that could be associated with improved reliability.

Since increasing reliability is generally accomplished by performing additional (and perhaps more detailed) design for reliability activities, adding redundancy, using higher quality components, and performing additional development and reliability growth testing, there is naturally an impact on the Design and Production (D&P) cost.

Figure 1 presents a notional relationship between the Goal MTBF and D&P cost. An exponential relationship was used since it is generally accepted that it becomes increasingly difficult and more expensive to make marginal improvements in MTBF as values increase. It is also recognized that this relationship will vary by program depending on many factors, including the nature of the technology and complexity of the system.

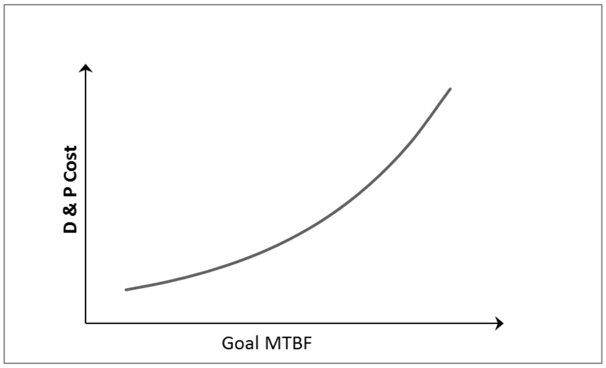

Figure 1 – Notional Relationship between the Goal MTBF and D&P Cost

Figure 2 presents a notional relationship between the Goal MTBF and reliability demonstration testing cost. This notional relationship assumes a constant warfighter requirement and that the investment cost in test planning and preparation is relatively small when compared to the total test program cost. Therefore, the cost/hour of testing is generally constant; so doubling test hours would essentially double test cost. For this discussion it is also assumed that there is generally a linear relationship between test hours and Goal MTBF.

As test hours (and cost) are decreased, the Goal MTBF increases since the population of experienced failures will naturally be smaller, which means that the "true" MTBF of the system must be greater in order to achieve the desired confidence that the MTBF requirement is met. In other words our system reliability must be very high to pass a limited duration test since the sample size of failures will be small. Conversely, when the reliability demonstration test time is increased (and therefore test cost is increased) the Goal MTBF can be decreased, but still provide the desire confidence that the MTBF requirement is met.

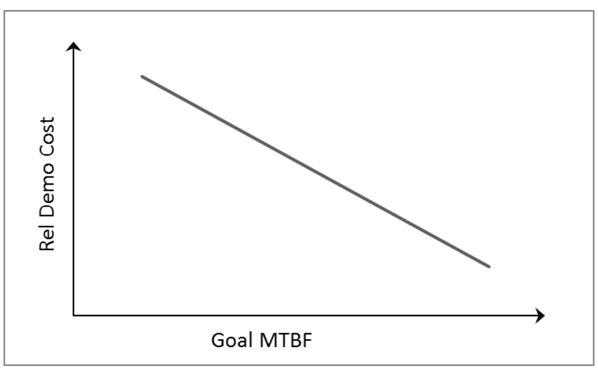

Figure 2 – Notional Relationship between the Goal MTBF and Reliability Demo Test Cost

4 A COST/BENEFIT METHODOLOGY

If we accept that there exists some relationship between the Goal MTBF, resulting D&P, and reliability demonstration testing cost, then it follows that we should attempt to define a Goal MTBF that considers a balance between bearing the cost (and schedule impacts) of over-design with the cost of additional testing.

The combined cost of D&P and reliability demonstration testing should be considered when establishing the Goal MTBF, which ultimately determined the required "design-to" values for the system developer to meet.

While that seems like a straightforward methodology for making sound investment in the systems and reliability demonstration test program, there are other variables and challenges that must also be considered.

4.1 Confidence Levels

Is 80% confidence needed? One of the drivers of MTBF requirement inflation is the Producer and Consumer confidence values. There may be programs where the only financially meaningful way forward is to be willing to accept something lower than 80% confidence levels. This does not mean that the system will not meet the warfighter's requirements, but when a lower confidence value is used the lower Goal MTBF will likely provide some savings in the D&P cost (which could be used for design changes if needed).

4.2 Reliability Demonstration Test Time

What is considered "demonstration time"? The current DoD policy is to only include independently conducted operationally significant test hours in the time used for reliability demonstration testing. Those hours are typically during Operational Evaluation (OPEVAL), Operational Assessment (OA), and Initial Operational Test & Evaluation (IOT&E) events. There are, however, normally a significant number of test hours accumulated during Development Testing (DT) and Reliability Growth Testing (RGT) that could be used to improve confidence is the system's reliability and potentially reduce some of the inflation that currently goes into the Goal MTBF. There are activities underway at US Army Tank & Automotive Research & Development Center (TARDEC) to define a methodology for capitalizing on these other test hours to help demonstrate the system's reliability [6]. Once these methodologies are available the next step will be to validate them using previous test data and generate support for their application within the DoD community.

5 WHAT IS NEEDED

The detailed incorporation of cost considerations in the development of reliability requirements, growth planning, and demonstration testing is not easy, but it should start prior to Milestone A during development of the RAM-C Rationale Report and Goal MTBF included in the system specification. At that phase of a program the decision making of requirements developers would greatly benefit from the insight on how establishment of reliability requirements (including the effect of inflation/over-design to demonstrate the requirement with 80% confidence) affects D&P, reliability demonstration testing, and sustainment cost.

Providing the requirements developers with the ability to apply a cost/benefit methodology when defining the reliability requirements will require quantification of the relationships discussed in this paper between the Goal MTBF and the cost associated with D&P and reliability demonstration tests. Additional studies and work is needed in this area. It will certainly prove to be challenging since these relationships will likely vary from program to program based on several factors, including the complexity, technology, maturity level, etc., but the results will help move Government and industry toward more affordable systems that meet (but don't necessarily exceed) the warfighter's requirements.

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Steve Rogers is Chief Operating Officer (COO) and Technical Director with Acquisition Logistics Engineering (ALE) and a Certified Professional Logistician (C.P.L.). He earned a Bachelor of Science in Mechanical Engineering from The Ohio State University in 1989. He has 25 years of life cycle engineering experience and is responsible for ensuring the successful execution of all projects at ALE and the planning and performing of Life Cycle Engineering Analyses, including Systems Analysis, Life Cycle Cost (LCC), Integrated Logistic Support (ILS), Reliability, Maintainability, Safety, Logistic Support Analysis (LSA), and Performance Based Logistics (PBL). His duties include review and oversight of the technical, schedule, and budget aspects of ALE projects and the integration of system analysis; LCC; Reliability, Maintainability, and Supportability (RMS); LSA with product design; and development of tools and techniques to streamline the process.

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