DESCRIPTION OF AMSAA'S RELIABILITY TOOLS

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US Army Materiel Systems Analysis Activity
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1. INTRODUCTION

To help manage reliability activities throughout the development life cycle, the U.S. Army Materiel Systems Analysis Activity (AMSAA) has developed reliability Scorecards, reliability growth planning, tracking, and projection models, and reliability test planning tools. These models are written in Microsoft Excel and are a replacement for the AMSAA Visual Growth Suite CD. The models are available free of charge to U.S. Government personnel and their contractors. To request a copy of the AMSAA reliability tools, please visit our website at www.amsaa.army.mil/CRG.html to obtain a Model Request Form.

2. RELIABILITY SCORECARDS

As a part of the Department of Defense (DoD) Reliability Improvement Working Group, AMSAA developed the Reliability Scorecard to standardize the assessment of a program's path to meeting its reliability requirements. Additionally, AMSAA offers a Software Reliability Scorecard to allow for an assessment of software-intensive systems.

2.1 AMSAA Reliability Scorecard

The AMSAA Reliability Scorecard examines a supplier's use of reliability best practices, as well as the supplier's planned and completed reliability tasks. The Scorecard is important for tracking the achievement of reliability requirements and rating the adequacy of the overall Reliability Program. An early Scorecard assessment may be based solely on a Reliability Program Plan, but as time progresses, the Scorecard assessment will become more accurate if information from technical interchange meetings, a Reliability Case, and results from early reliability tests, are included. The Reliability Case documents the supplier's understanding of the reliability requirements, the plan to achieve the requirements, and a regularly-updated analysis of progress towards meeting the requirements.

There are 40 separate elements among the eight categories in the AMSAA Reliability Scorecard. The eight categories are: Reliability Requirements and Planning, Training and Development, Reliability Analysis, Reliability Testing, Supply Chain Management, Failure Tracking and Reporting, Verification and Validation, and Reliability Improvements. Each element within a category can be given a risk rating of high, medium, or low (red, yellow, or green) or not evaluated (gray). The Scorecard weights the elements, normalizes the scores to a 100-point scale, and calculates an overall program risk score and eight category risk scores.

2.2 AMSAA Software Reliability Scorecard

The AMSAA Software Reliability Scorecard extends and complements the general reliability scorecard by examining an individual software development effort and assessing the level of risk associated with the software reliability practices being applied. It also complements existing software approaches, such a CMMI, by examining reliability-specific practices within an individual software project.

The Software Scorecard provides a structured and transparent approach to software reliability and maintains a consistent design with the general reliability scorecard. A total of 57 specific elements are examined across seven key areas of software development and sustainment: Program Management, Requirements Management, Design Capabilities, System Design, Design for Reliability (DfR), Test and Acceptance, and Fielding and Sustainment.

The Software Scorecard provides a structured and transparent instrument for assessing the health of a software development effort in regards to software reliability and is useful in isolating areas for further analysis and work. The discussion and reflection that occurs as the instrument is applied enables multiple disciplines to see the value of good reliability issues and practices in a structured way. The Software Scorecard is invaluable to uncovering areas of weakness so that technical resources can be best prioritized and, subsequently, more reliable software can be developed.

3. RELIABILITY GROWTH PLANNING MODELS

Reliability growth planning addresses program schedules, amount of testing, resources available, and the realism of the test program in achieving the requirements. The planning is quantified and reflected in the construction of a reliability growth program planning curve, which establishes interim reliability goals throughout the program. AMSAA offers two reliability growth planning tools – PM2-Continuous and PM2-Discrete.

3.1 Planning Model based on Projection Methodology – Continuous (PM2-C)

3.1.1 Purpose

The purpose of PM2-Continuous is to develop a system-level reliability growth planning curve that incorporates the developmental test schedule and corrective action strategy. The planning curve and associated steps serve as a baseline which reliability assessments may be compared against, possibly highlighting the need for reallocation of resources. Unlike the AMSAA Crow Planning Model, the PM2-Continuous model does not have a growth rate parameter, nor is there a comparable quantity. Furthermore, PM2-Continuous utilizes planning parameters that are directly influenced by program management, which include:

a. M_I , the planned initial system MTBF;
b. MS, the Management Strategy, which is the fraction of the initial failure rate addressable via corrective action;
c. M_G, the MTBF goal for the system to achieve at the conclusion of the reliability growth test;
d. μ_d, the planned average FEF of corrective actions;
e. T, the duration of developmental testing; and
f. the average lag time associated with corrective actions.

3.1.2 Assumptions

The assumptions associated with PM2-Continuous include:

a. Initial B-mode failure rates $\lambda_1,\ldots,\lambda_k$ constitute a realization of an independent random sample $\Lambda_1,\ldots,\Lambda_k$ such that $\Lambda_i \sim$ gamma (α, β) for each $i = 1,\ldots,k$ where the density function is:

$$f_\Lambda(\lambda) = \frac{\lambda^\alpha e^{-\frac{\lambda}{\beta}}}{\alpha!\,\beta^{\alpha+1}}$$

As a rule of thumb, the potential number of B-modes should be at least five times the number of B-modes that are expected to be surfaced during the planned test period.

This assumption models mode-to-mode variation with respect to the initial B-mode rates of occurrence. The assumption for complex systems (i.e., for large k) also gives rise to the form of the function utilized in PM2-Continuous for the number of B-modes that are expected to be surfaced in t test hours. The functional form is reflective of the modeled B-mode initial failure rate variation. This same functional form can be arrived at without this assumption. For one such alternate approach that leads to this functional form, see AMSAA Technical Report TR-2006-09.

b. B-mode first occurrence times $t_1, \ldots, t_k$ constitute a realization of an independent distributed random sample $T_1, \ldots T_k$ such that $T_i \sim$ Exponential (λ_i) for each $i = 1, \ldots, k$;

c. Each failure mode occurs independently and causes system failure; and

d. Corrective actions do not create new failure modes.

3.1.3 Limitations

The limitations associated with PM2-Continuous include:

a. The portion of testing utilized for reliability growth planning should be reflective of the OMS/MP;

b. Need to have a realistic test schedule that determines the number of test hours per vehicle per month over the planned testing period; and

c. Need to have CAPs specified within the planned test schedule.

3.1.4 Benefits

The benefits associated with PM2-Continuous include:

a. Can determine the impact of changes to the planned test schedule and associated CAPs;

b. Measures of programmatic risk are not sensitive to the length of the initial test phase (which is a limitation of the AMSAA Crow Planning Model);

c. Can use different average corrective action lag time for each test phase;

d. Provides an MTBF target to track against;

e. Can be applied to programs with limited opportunities for implementation of corrective actions; and

f. Utilizes planning parameters that are directly influenced by program management.

3.2 Planning Model based on Projection Methodology – Discrete (PM2-D)

3.2.1 Purpose

Based on research conducted by J. B. Hall in his PhD Dissertation and documented in ATEC TN, "Reliability Growth Planning for Discrete Systems," PM2-Discrete was developed. PM2-Discrete is the first methodology specifically developed for discrete systems and is also the first quantitative method available for formulating detailed plans in the discrete usage domain. The model has the same conditions of use as the continuous PM2 model, except for the usage domain. PM2-Discrete utilizes planning parameters that are directly influenced by program management, which include:

a. R_I, the planned initial system reliability;

b. MS, the Management Strategy, which in the discrete case is a value between 0 and 1 that decomposes R_I into the factors R_A and R_B (which are defined below);

c. R_G, the goal reliability for the system to achieve at the conclusion of the reliability growth test;

d. μ_d, the planned average FEF of corrective actions;

e. T, the duration of developmental testing; and
f. average delay associated with corrective actions.

3.2.2 Assumptions

The assumptions associated with PM2-Discrete include:

a. Initial B-failure mode probabilities of occurrence $p_1,\ldots,p_k$ constitute a realization of an independent and identically distributed (*iid*) random sample $P_1,\ldots,P_k$ such that $P_i \sim Beta(n,x)$ for each $i=1,\ldots,k$, with Probability Density Function (PDF) parameterization

$$f(p_i) \equiv \begin{cases} \dfrac{\Gamma(n)}{\Gamma(x)\cdot\Gamma(n-x)}\cdot p_i^{x-1}\cdot(1-p_i)^{n-x-1} & p_i \in [0,1] \\ 0 & \text{otherwise} \end{cases}$$

With the shape parameters n and x where $\Gamma(x) \equiv \int_0^\infty t^{x-1}\cdot e^{-t}dt$ is the Euler gamma function. The associated mean, and variance of the P_i are given respectively by,

$$E(P_i) = \frac{x}{n}$$

and

$$Var(P_i) = \frac{x\cdot(n-x)}{n^2\cdot(n+1)}$$

b. The number of trials $t_1,\ldots,t_k$ until B-failure mode first occurrence constitutes a realization of a random sample $T_1,\ldots,T_k$ such that $T_i \sim Geometric(p_i)$ for each $i=1,\ldots,k$
c. Potential failure modes occur independently and cause a system failure
d. Corrective actions do not create new failure modes.

3.2.3 Limitations

The limitations associated with PM2-Discrete include:

a. The portion of testing utilized for reliability growth planning should be reflective of the OMS/MP;
b. Need to have a realistic test schedule that determines the number of trials planned over the test period; and
c. Need to have CAPs specified within the planned test schedule.

3.2.4 Benefits

The benefits associated with PM2-Discrete include:

a. PM2-Discrete can determine the impact of changes to the planned test schedule and associated CAPs.
b. PM2-Discrete can use different average corrective action delay periods for each test phase.
c. PM2-Discrete provides a reliability target to track against.

d. PM2-Discrete can be applied to programs with limited opportunities for implementation of corrective actions.

e. PM2-Discrete offers several reliability growth management metrics of basic interest including:

   i. Expected number of failure modes observed through trial *t*;
   ii. Expected reliability on trial *t* under instantaneous failure mode mitigation;
   iii. Expected reliability growth potential;
   iv. Expected probability of failure on trial *t* due to a new B-mode; and
   v. Expected probability of failure on trial *t* due to a repeat B-mode expressed as a fraction of the initial B-mode probability of failure in the absence of failure mode mitigation.

4. RELIABILITY GROWTH TRACKING MODELS

Reliability growth tracking is an area of reliability growth that provides management the opportunity to gauge the progress of the reliability effort for a system. Management's strategy for incorporating corrective actions will determine if a reliability growth tracking model is appropriate. AMSAA offers one reliability growth tracking model – RGTM-C.

4.1 AMSAA Reliability Growth Tracking Model – Continuous (RGTM-C)

4.1.1 Purpose

The purpose of the AMSAA RGTM-C is to assess the reliability improvement (within a single test phase) of a system during development, for which usage is measured on a continuous scale. The model may be utilized if individual failure times are known, or if failure times are only known to an interval (grouped data).

4.1.2 Assumptions

The assumptions associated with the AMSAA RGTM-C are:

a. Test duration is continuous and

b. Failures within a test phase occur according to a NHPP with power law mean value function.

4.1.3 Limitations

The limitations associated with the AMSAA RGTM-C include:

a. The model will not fit the test data if large jumps in reliability occur as a result of the applied corrective action implementation strategy;

b. The model will be inaccurate if the testing does not adequately reflect the OMS/MP;

c. If a significant number of non-tactical fixes are implemented, the growth rate and associated system reliability will be correspondingly inflated as a result; and

d. With respect to contributing to the reliability growth of the system, the model does not take into account reliability improvements due to delayed corrective actions.

4.1.4 Benefits

The benefits associated with the AMSAA RGTM-C include:

a. The model can gauge demonstrated reliability versus planned reliability;

b. The model can provide statistical point estimates and confidence intervals for MTBF and growth rate; and
c. The model allows for statistical goodness-of-fit testing.

5. RELIABILITY GROWTH PROJECTION MODELS

A reliability projection is an assessment of reliability that can be anticipated at some future point in the development program. The projection is based on the achievement to date and engineering assessments of future program characteristics. Projection is a particularly valuable analysis tool when a program is experiencing difficulties because it enables investigation of program alternatives. AMSAA offers two reliability growth projection models for continuous-use systems, ACPM and AMPM, and one reliability growth projection model for discrete-use systems, ADPM.

5.1 AMSAA-Crow Projection Model (ACPM)

5.1.1 Purpose

The purpose of ACPM is to estimate the system reliability at the beginning of a follow-on test phase by taking into consideration the reliability improvement from delayed fixes.

5.1.2 Assumptions

The assumptions associated with ACPM include:

a. Test duration is continuous;
b. Corrective actions are implemented as delayed fixes at the end of the test phase;
c. Failure modes can be categorized as either A-modes and B-modes;
d. Failure modes occur independently and cause system failure;
e. There are a large number of potential B-modes;
f. The number of B-modes surfaced can be approximated by a NHPP with power law mean value function;
g. The time to first occurrence is exponentially distributed for each failure mode;
h. The number of A-mode failures by test duration t conforms to a homogeneous Poisson process over the test phase; and
i. The number of B-mode failures by test duration t conforms to a homogenous Poisson process over the test phase.

5.1.3 Limitations

The limitations associated with ACPM include:

a. All corrective actions must be delayed;
b. FEFs are often a subjective input; and
c. Projection accuracy can be degraded via reclassification of A-modes to B-modes.

5.1.4 Benefits

The benefits associated with ACPM include:

a. The ability to project the impact of delayed corrective actions on system reliability; and
b. The projection takes into account the contribution to the system failure intensity due to unobserved B-modes.

5.2 AMSAA Maturity Projection Model (AMPM)

5.2.1 Purpose

The purpose of AMPM is to provide an estimate of the projected reliability following the implementation of both delayed and non-delayed fixes. The model also provides estimates of the following important reliability growth metrics:

a. B-mode initial failure intensity
b. expected number of B-modes surfaced
c. percent surfaced of the B-mode initial failure intensity surfaced
d. rate of occurrence of new B-modes

5.2.2 Assumptions

The Assumptions associated with AMPM include:

a. Test duration is continuous;
b. Failure modes independently occur and cause system failure;
c. Failure modes can be classified as either A-modes or B-modes;
d. Corrective actions are implemented prior to the time at which projections are made; and
e. Initial B-mode failure rates can be modeled as a realization of a random sample from a gamma distribution.

5.2.3 Limitations

The limitations associated with AMPM include:

a. FEFs are often a subjective input; and
b. Projection accuracy can be degraded via reclassification of A-modes to B-modes.

5.2.4 Benefits

The benefits associated with AMPM include:

a. Corrective actions can be implemented during test or can be delayed until the end of test;
b. Reliability can be projected for future milestones;
c. The model can project the impact of delayed corrective actions on system reliability;
d. The projection takes into account the contribution to the system failure rate due to unobserved B-modes;
e. In situations where there is an apparent steepness of cumulative number of B-modes versus cumulative test time over an early portion of testing after which this rate of occurrence slows, there is methodology to partition the early modes from the remaining modes. These early B-modes must be aggressively and effectively corrected.
f. Additionally methodology exists to handle cases where there is an early "gap" or if there appears to be a difference in the average FEFs in early or start-up testing versus the remainder of testing (an apparent or visual difference in failure rate in the initial testing).

5.3 AMSAA Discrete Projection Model (ADPM)

5.3.1 Purpose

The purpose of the ADPM is to provide an estimate of the projected reliability following the implementation of both delayed and non-delayed fixes for discrete (one-shot) systems. The model also provides estimates of the following important reliability growth metrics:

a. The reliability growth potential;
b. Probability of a new failure mode occurring; and
c. Fraction surfaced of the system's initial probability of failure.

5.3.2 Assumptions

The assumptions associated with ADPM include:

a. Test duration is discrete;
b. Failure modes occur independently and cause system failure;
c. Failure modes can be classified as either A-modes or B-modes; and
d. Initial failure mode probabilities can be modeled as a realization of a random sample from a beta distribution.

5.3.3 Limitations

A limitation associated with the ADPM is FEFs are often a subjective input and can affect associated projections.

5.3.4 Benefits

The benefits associated with ADPM include:

a. Corrective actions can be implemented during the test or can be delayed until the end of test;
b. Reliability can be projected for future milestones;
c. The system's growth potential can be compared to program objectives; and
d. The projection takes into account the contribution of the system's probability of failure due to unobserved modes.

6. RELIABILITY TEST PLANNING TOOLS

When choosing the duration for a reliability demonstration test, it is critical for program managers to consider the reliability requirement, the desired confidence level in IOT, and the desired probability of acceptance in IOT. To aid in this process, AMSAA developed two reliability test planning tools – IPT-C and IPT-D. These two tools allow program management to effectively plan for a fixed-length, fixed-configuration demonstration test, such as the IOT.

6.1 AMSAA Initial Operational Test (IOT) Planning Tool – Continuous (IPT-C)

6.1.1 Purpose

The purpose of the IPT-C is to help the user choose an appropriate IOT profile and obtain the necessary metrics for developing a reliability program plan. The IPT-C contains two tools called the IOT Planner – Continuous and the OC Curve Plotter – Continuous. These tools can:

a. Aid in conducting tradeoff analyses involving the reliability demonstration test parameters, the requirement parameters, and the associated risk parameters for planning reliability demonstration tests;

b. Display possible IOT test durations based on the required inputs and the associated risks; and
c. Calculate the goal MTBF needed in IOT (M_R^+) using OC curve methodology.

6.1.2 Assumptions

The assumptions associated with IPT-C include:

a. The number of failures in the IOT is Poisson distributed, with a constant failure rate of $1/M_R$, given by

$$P(X \leq c) = \sum_{x=0}^{c} \frac{\left(\frac{T_{IOT}}{M_R}\right)^x e^{-\left(\frac{T_{IOT}}{M_R}\right)}}{x!}$$

where M_R is the MTBF requirement, c is the maximum allowable number of failures, T_{IOT} is the amount of test hours in the IOT, and x is the number of failures; and
b. The system maintains a constant configuration during IOT and no corrective actions are implemented during IOT.

6.1.3 Limitations

The limitations associated with IPT-C include:

a. The testing conducted during the IOT should be reflective of the Operational Mode Summary/Mission Profile (OMS/MP); and
b. The maximum allowable number of failures in IOT that the tool can provide output for is 100.

6.1.4 Benefits

The benefits associated with IPT-C include:

a. IOT Planner – Continuous tool can help the user choose an appropriate IOT test duration that satisfies the MTBF requirement and Consumer/Producer risks;
b. OC Curve Plotter – Continuous tool can verify that the user's inputted IOT profile is valid;
c. Both tools provide the user with important metrics associated with the IOT profiles (e.g., the goal MTBF needed in IOT); and
d. Both tools provide the user with the necessary metrics to develop a reliability growth plan (specifically M_R^+).

6.2 AMSAA Initial Operational Test (IOT) Planning Tool – Discrete (IPT-D)

6.2.1 Purpose

The purpose of the IPT-D is to help the user choose an appropriate IOT profile and obtain the necessary metrics for developing a reliability program plan. The IPT-D contains two tools called the IOT Planner – Discrete and the OC Curve Plotter – Discrete. These tools can:

a. Aid in conducting tradeoff analyses involving the reliability demonstration test parameters, the requirement parameters, and the associated risk parameters for planning reliability demonstration tests;
b. Display possible IOT test durations based on the required inputs and the associated risks; and

c. Calculate the goal reliability needed in IOT (R_R^+) using OC curve methodology.

6.2.2 Assumptions

The assumptions associated with IPT-D include:

a. The number of failed trials in the IOT is binomially distributed, with a constant probability of failure in any given trial, where trials are independent,

$$P(X \leq c) = \sum_{x=0}^{c} \binom{n}{x} (1-R)^x R^{n-x}$$

where R is the reliability, c is the maximum allowable number of failed trials, n is the total number of trials, and x is the number of failed trials; and

b. The system maintains a constant configuration during IOT and no corrective actions are implemented during IOT.

6.2.3 Limitations

The limitations associated with IPT-D include:

a. The testing conducted during the IOT should be reflective of the Operational Mode Summary/Mission Profile (OMS/MP); and

b. The maximum allowable number of failed trials in IOT that the tool can provide output for is 50.

6.2.4 Benefits

The benefits associated with IPT-D include:

a. IOT Planner – Discrete tool can help the user choose an appropriate IOT test duration that satisfies the reliability requirement and Consumer/Producer risks;

b. OC Curve Plotter – Discrete tool can verify that the user's inputted IOT profile is valid;

c. Both tools provide the user with important metrics associated with the IOT profiles (e.g., the goal reliability needed in IOT); and

d. Both tools provide the user with the necessary metrics to develop a reliability growth plan (specifically R_R^+).