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RELIABILITY GROWTH MODELS FOR NASA APPLICATIONS

Prepared By:	Vidya S. Taneja, Ph.D.
Academic Rank:	Professor
Institution:	Western Illinois University Department of Mathematics
NASA/MSFC:	
Office:	System Safety & Reliability
Division:	Reliability & Maintainability Engineering
Branch:	Analysis
MSFC Colleague:	Fayssal M. Safie, Ph.D. William C. Smith Frank Pizzano
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1. Objective: The first objective of any reliability growth study is Prediction of Reliability at some future instant. We are concerned with the current reliability estimate, growth rate, and whether it is possible to extrapolate the growth pattern in the future. From this we can estimate ultimate reliability to determine if future reliability requirements will be met. Also we might investigate how reliability growth of a system is related to factors such as: number of tests, cost, number and type of design changes, design reviews, etc. A second objective of any reliability growth study is statistical inference, estimation of reliability for reliability demonstration.

A cause of concern for the development engineer and management is that reliability demands an excessive number of tests for reliability demonstration. For example, the STME program requirements call for .99 reliability at 90% confidence for demonstration. This requires running 230 tests with zero failure if a classical binomial model is used. Therefore, more innovative techniques need to be used. Reliability growth models are potential candidates for more efficient testing.

It is therefore the objective of this study to explore the reliability growth models for reliability demonstration and tracking and their applicability to NASA programs.

2. Background: Technology has been characterized in the past two decades by the development of complex systems containing number of subsystems and components, and parts. At the present time it is realized that these complex designs carry within them the possibility of various types of error and malfunctions. The failure of a single inexpansive component may cause the failure of the entire system.

In the manufacturing of a complex system, such as Space Transportation Main Engine (STME), the initial prototypes will invariably have significant reliability and performance deficiencies. Consequently, such a system is subjected to a development testing. When a failure occurs, the cause is isolated and a corrective action is implemented.

Reliability tracking is a method for quantifying and monitoring a system reliability during the development phase through the collection and analysis of relevant data. Reliability tracking, in general, is not contractually required. However, the existence of a reliability tracking program during early development phases increases the likelihood that more problems will be resolved earlier in the program, thus reducing large costs later.

Reliability growth is the positive improvement in reliability due to changes in product design or the manufacturing process. Reliability growth is not automatic: it results only from Test-Analyze-And-Fix (TAAF). It is expected that this process of finding problems (design weakness) and fixing (design change) will result in increasing Time Between Failures (TBF).

Reliability managers have long been aware of the fact that the reliability of the systems should improve as it progresses through development but this growth will meet a targeted rate is always a concern. A reliability growth management program will furnish the manager with a mean to plan this growth and control its progress. Such a program also enables the manager to:

a. Take advantage of experience gained in previous programs
b. Evaluate different potential test plans and select the appropriate one;
c. Evaluate possible causes of failures and the appropriate corrective actions when an ongoing program is experiencing problems
d. Correctly evaluate the progress made by an ongoing program.

3. Reliability Growth Models: A Reliability Growth Model is an analytical tool used to monitor the reliability progress during the development program and to establish a test plan to demonstrate an acceptable System Reliability. Reliability growth models can be used for:

a. Determining the intensity of TAAF to reach reliability objectives;
b. Predicting whether stated reliability objectives will be achieved;
c. Tracking progress, correlating reliability changes with reliability activities; and
d. Planning for a reliability demonstration test; computing confidence limits.

At present there is no shortage of reliabiity growth models, the current problem is the lack of criteria for selecting the best for a particular application. For NASA applications we classify growth models in two groups, growth models for management and growth models for demonstration. The characteristics of each group is summarized as follows:

A. Characteristics of Growth Model for Management/Tracking:

a. Use of objective and subjective information
   - The model is based on engineering concepts and statistical concepts;

b. Prediction
   - The model can be used to forecast Reliability at Maturity from development data;

c. Asymptotic Value
   - the reliability growth value converges to a limiting value with increased time or sample value;

d. Adaptability
   - the model can be used for developmental and operational data
   - the model can adapt quickly to changes in data trends

e. Control
- The growth model can be used to evaluate growth management strategy. The reliability growth can be traced statistically, that is, actual growth follow the predicted growth curve.

B. Characteristics of a Growth Model for Demonstration:

a. Use of Objective Data
- The model uses actual test data to estimate the parameters of the reliability growth models;

b. Statistical Confidence
- Statistical Confidence is part of mathematical formulation of the models;

c. Model Goodness of Fit
- The goodness of fit between the reliability growth model and data can be checked statistically;

d. Prediction and Control
- Same as model used for reliability growth management.

4. Applications of Growth Models to NASA Programs

4.1 Space Shuttle Main Engine (SSME) reliability has been evaluated by Dr. Fayssal Safie [1] using reliability growth models. The main aim was to study the growth process for the SSME reliability growth for crit 1 failures during the operational phase of the program (1/1/79 to 12/31/90). In this study the growth parameter was used to check for reliability improvement and the derived reliability represents the demonstrated reliability of the SSME.

4.2 Space Transportation Main Engine (STME). A reliability demonstration test plan for STME can be developed using reliability growth and is under consideration now. This will use history of previous programs such as J-2, F-1, RL-10, SSME, H-1, etc. However, much more work needs to be done.

Also, we plan to develop a STME component/system reliability growth tracking procedure. The objective is to select the optimum reliability growth model to monitor reliability during development and predict growth patterns.

As a first step to accomplish this task Redstone Scientific Information Center was used to compile a bibliography of 65 references (books and articles) related to reliability growth. This literature covers the past 25 years of work on reliability growth modeling, assessment, tracking, prediction, and control. Due to space restriction, this list is not attached to this report but is available from MSFC, Analysis Branch, Reliability and Maintainability Division.

5. Recommendations: Reliability is the science of estimating, controlling, and managing the probability of failure. Thus, any high-tech space system can advantageously use methods of reliability. At present, the Department of Defense is using reliability growth, tracking, management, and demonstration for various military projects. NASA needs to invest more time and expand effort in this area.

At any time, both the achieved reliability and its growth trend must be identifiable quantitatively to permit corrective action to achieve specified reliability goals. There is probably no single best approach to high reliability since each application is likely to have unique requirements. Reliability growth modeling can be useful for diverse kinds of equipment. But, NASA programs are very unique and their systems are complex requiring high reliability. Therefore, applications of growth models to NASA programs need to be developed carefully.

The ability to predict the reliability of a system within reasonably close limits, during development and operations is a significant requisite to achieving the very high reliability goals set forth for various NASA systems. It is therefore recommended that NASA develops a manual in the reliability growth area for NASA applications. Two main aims for this new venture are:

a. To evolve a reliability growth modeling analytical procedure which would provide guidance with which to confidently assess, predict, and control the reliability growth of NASA programs.

b. New statistical methodology for unique NASA programs be explored and developed.

When completed, this manual will serve as a tool for designers and managers to improve reliability through the different phases of a NASA program.

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7. References:

[1] Safie, Fayssal M. "SSME Reliability Growth Study" Presentation, MSFC, Reliability Analysis Branch, August 1990

[2] MIL-HDBK-189: Reliability Growth Management, Available from HQ, U.S. Army Commmunications Research and Development Common, Fort Monmouth, NJ, 1981