THE RELIABILITY ENGINEER PRIMER

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PLAUTUS

Reliability Testing

Reliability testing is reviewed in the following topic areas:

- **Reliability test planning**
- **Development testing**
- **Product testing**

Reliability Testing Introduction

Reliability testing is an activity carried out by both the supplier (manufacturer) and customer. There are many reasons for performing reliability testing. The main reasons are:

- To induce and detect failure modes and implement corrective action
- To determine if items or systems meet specified reliability requirements
- To compare estimated failure rates to actual failure rates
- To monitor reliability growth over time
- To determine the safety margin in a design
- To estimate MTBF or MTTF values
- To identify weaknesses in the design or parts

O'Connor (2002)[35] states that reliability testing is part of an integrated test program involving:

- Statistical testing, to optimize the design of product and processes
- Functional testing, to confirm the design
- Environmental testing, to ensure operation under projected conditions
- Reliability testing, to ensure that the product will operate for its expected life
- Safety testing, to ensure product safety for humans, animals, or property

For each program or product, an engineer or project manager should have responsibility and authority for carrying out the objectives. An inherent conflict that arises is that uncovered failures will slow the completion of the program. However, failures are required in order to detect weaknesses in the design or in the production process. An ideal test program will produce the discovery of every failure mode.

Reliability Test Planning

Reliability test planning is reviewed in the following topic areas:

- **Reliability test strategies**
- **Test environment**

Reliability Test Strategies

The project manager must consider the following factors in the test plan design:

- **How critical is the product?**
- **Are safety and reliability a concern?**
- **Does the customer need a certain level of reliability?**
- **How mature is the design?**
- **Are new technologies or processes involved?**
- **How complex is the product?**
- **What are the environmental extremes involved?**
- **What is the budget for testing?**
- **Are the equipment or facilities able to perform test conditions?**
- **How many items are available for testing?**
- **What is the existing design reliability?** **(*Reliability Toolkit*, 1993)[38]**

Planning should start as early as possible in the design process. It would be ideal to have test equipment available for the first prototypes with built in test points. Information from the design phase concerning reliability prediction, FMEAs, stress analysis, parameter variation analysis, fault tree analysis, etc., will aid in preparing the reliability test plan. Use of existing information can focus the test plan in detecting failure modes or concerns.

O'Connor (2002)[35] states that it is rare to test fewer than four items. A typical sample size would be 5 to 20. Of course, cost will be a major factor for large, complex, expensive, one-onlys, such as power stations, space shuttles, etc. Generally, mechanical devices are subject to wear, fatigue, or corrosion, so accelerated testing would be a good choice. Electronic components will enter the constant hazard rate, after the early burn-in period, so long duration testing is not a good choice for these products.

Reliability Test Strategies (Continued)

In planning the testing program, the project manager will have additional information available to process. Ireson (1996)[12] lists them as:

- Customer requirements
- Drawings, specifications
- Test plans, procedures
- Tests and inspections
- Cost analysis
- Tolerance studies
- Spare parts lists
- Critical parts lists
- Field service test plans
- Test facilities
- Capability lists
- Plant layout

A tentative test plan is developed, but will be revised at frequent intervals due to changes in design concepts, production techniques, failure feedback, or new failure modes. The test plan and schedule should be charted. The test plan should include:

- A test plan for each item (characteristics, specifications, quantities, environments and documented procedures)

- A parameters spreadsheet which guides the testing of materials, dimensions, colors, power levels, resistances, sensitivities versus the input stresses of vibration, cycling, shock, acceleration, and temperature

An example reliability test schedule is shown in Table 7.1.

	Month						
Item	0	1	2	3	4	5	6
Develop test plan	x						
Hazard analysis		x					
Reliability test procedures				x			
Design test equipment			x				
Build test equipment			x				
Equipment test procedures				x			
Prototype tests				x			
Revised tests					x		
Final test						x	
Test report							x

Table 7.1 Sample Reliability Test Program Schedule

Reliability Test Strategies (Continued)

Additional items for each specific test can be added to the test plan. Different checklists can be developed and used during the test which might include: equipment operations, on/off cycles, operational modes, exercising methods, performance verification procedures, failure event procedures, equipment adjustments and preventive maintenance.

The *Reliability Toolkit* (1993)[38] provides a test plan outline which includes the following steps:

Topic	Description
Purpose and scope	The test objectives, range of testing
References	A list of applicable reference documents
Test item facilities	Sketches of system layout, identification of units for testing, test location, security
Test requirements	The test length, number of units for testing, number of allowable failures, description of acceptance criteria
Test schedule	The start date, finish date, hours per day, test days per week
Test conditions	Thermal cycles, vibration surveys, test mounting methods, test chamber capabilities, descriptions of units under test for calibration, test duty cycles
Test monitoring	Test software and validation method, monitoring of all units, test equipment parameters
Test participation	Description of test management structure, participant functions and responsibilities
Failure definitions	Key term definitions that will be used in the test: design defects, manufacturing defects, intermittent failures, failures from overstressing, etc.
Test ground rules	Ground rules for: transient failures, classification of failure, malfunctions, test time accumulation, design changes to equipment
Test documentation	Test logs required: equipment data sheets, test logs, failure summary records, failure reports

Types and Applications of Reliability Testing

Demonstration Tests

The type of demonstration test performed depends upon the stage or maturity of the product. These tests may be run in the prototype or development stage. During testing, estimates of MTTF or MTBF are obtained for comparison to the requirements. These tests may also be run after significant design changes are made to indicate if reliability was enhanced or degraded by the change.

Qualification Testing

This is a rigorous test for determining if a design is acceptable for the intended function. Qualification tests in many cases include aspects of vibration, humidity, shock, temperature cycling and other environmental considerations the item will see in use.

Acceptance Testing

Acceptance testing is statistically derived to determine if an item is to be accepted for use. This method of testing does not provide estimates of MTBF, MTTF, fraction or percentage acceptable, or any other quantifiable measure.

Performance Testing

Performance testing is conducted on completed designs and normally manufactured items to verify the reliability predictions and test results in the preproduction phase. This testing provides a benchmark for comparison of previous activities to see if they are effective in delivering a design that meets reliability requirements.

Failure Free Testing

When performing an acceptance test on one shot devices, or testing if devices work in a given application, zero failure testing can provide the information on reliability levels at a given level of confidence. This allows for determining the appropriate sample size to meet both reliability and confidence requirements. Failure free testing is most appropriate when one has a high confidence that the item(s) meet the requirements.

Types and Applications of Testing (Continued)

Screening

Screening tests are 100% tests performed with the intent of eliminating the infant mortality period. By eliminating the infant mortality period, the yield on finished products is improved, throughput is enhanced, and a higher reliability of systems and products is obtained. Piece part screening on electronic parts is most commonly performed per MIL-STD-883 (1996)[30].

As components get assembled into more complex configurations, the screening tests become more sophisticated. Subassemblies may see time and temperature cycling while output performance is measured. Larger systems will see run in, burn in, debugging as well as field use simulation. On larger systems, the goal is to stabilize the system prior to shipment to the customer.

Development Tests

Testing of the new product design is usually performed at various periods to verify progress. The testing is an essential part of the research and design process. Designs are rarely perfect and engineers are not able to predict every ramification or potential failure mode that would arise from new combinations.

Setting of Tolerances

The setting of tolerances is of concern. Tests are performed at several levels from assembly to the final stage. There exists the testing of attributes or characteristics in which measurement drift can allow marginal items to advance. The “funnel of tolerances” concept is used to retain tolerance control at each level of manufacturing. The tolerances of an attribute are set in a funnel arrangement, whereby, each immediate lower level is 5% (typically) tighter. The tightest tolerance will be at the lowest level or start of assembly. (Ireson, 1996)[12]

Example 7.1: For a power supply, the target power is 5 amperes. If there are 3 stages in the assembly process, starting with the vendor, the vendor must supply a power supply to be tested at 5 amps, +/-5%. The initial assembly step must provide a tested value of 5 amps, +/- 5.25%. The second step must be at 5 amps, +/-5.5%, and the final step, 5 amps, +/-5.8%. This example uses a 5% funnel for the amperes.

Types and Applications of Testing (Continued)

Attributes

The selection of attributes to be tested is determined through a combination of:

- **A need to demonstrate ability to function**
- **A need to demonstrate reliability**
- **Meeting costs for testing**
- **Meeting time factor for testing**
- **Availability of test equipment and personnel**
- **Meeting customer requirements**
- **A need for interchangeability**
- **A need to optimize process and quality control**
- **A need to attain the required reliability**
- **To balance the cost of replacement and testing** (Ireson, 1996)[12]

Classification of Characteristics

Functional attributes can be classified into categories. Military standard DOD-STD-2101(OS), *Classification of Characteristics*, uses: critical, major, or minor classifications based on coordination, life, interchangeability, function, and safety (CLFS). The classifications are:

Critical: A defective item will have an adverse effect on safety
Major: There will be a significant degradation in performance
Minor: All other effects (Ireson, 1996)[12]

Sampling Versus 100% Testing

Production assessment testing is performed on samples drawn from production, while production acceptance testing is 100% testing on all production. Sampling for attributes characteristics can be done using ANSI/ASQ Z1.4 and for variables data using ANSI/ASQ Z1.9. Sampling is not as valid statistically with small lots. A combination of probability and failure costs need to be considered and weighed. For small lots, sampling may be based on:

- **The tolerance of risk**
- **The uniformity of the process**
- **The potential liability of a failure**
- **The ability to produce needed test items**
- **The cost of test items and the test itself** (Ireson, 1996)[12]

Types and Applications of Testing (Continued)

Test Procedures

Test procedures are required for the proper execution of the test plan. The more important reliability is to the project, the more important procedures must be correct. The proper amount of detail and control must be in the procedures. There are 3 areas that the procedures must address:

1. **Calibration: the test equipment must be calibrated and traceable back to the National Institute of Standards and Technology. There are three types of calibration:**

    - **Calibration of individual instruments: As measured in the plant calibration lab or on the floor.**

    - **Calibration of systems of complex test or environmental equipment: Usually performed in place.**

    - **Calibration of standards: The comparing of each standard to one of higher accuracy in the same or a higher-level lab.**

    The normal rule of thumb ratio of accuracy for each level of accuracy is 10:1.

2. **Proofing the test equipment: To demonstrate that the test equipment can perform its intended function. Proofing is a key item, the first time a new equipment design is used in conjunction with new product hardware.**

3. **The test procedure: A description in detail of the tools, parts, adjustments, hook ups, data sheets, tools, and materials required for the test.**

(Ireson, 1996)[12]

Types and Applications of Testing (Continued)

Test to Failure

The easiest test plan to conceive and understand is the "test to failure" or complete testing approach. In this kind of test the selected number of units are placed on test and run until all have failed. Then the mean time to failure (MTTF) is simply:

$$\text{MTTF} = \frac{\sum\left(t_1, t_2, \ldots, t_N\right)}{N}$$

Where: t_1, t_2, etc. is the failure time for each individual unit
N is the total number of units

Testing to failure is frequently selected when all the failure modes are not already known. Thus, the testing to failure of a number of units has the potential of revealing failure modes that were not expected. This is particularly useful in early development (i.e. prototype testing or early development testing).

The main disadvantage to this testing is the length of time the test will take. If the unit has a very large mean time to failure, the test can stretch far beyond reasonable limits. To combat this, tests are often performed under severe stress conditions to hasten failure. This is called degradation testing.

Degradation Testing

Degradation testing is the use of enhanced stress to shorten the required test time. This is fairly easily and reliability done for electronic components (Arrhenius model) where elevated temperatures are used. Other elevated stress tests for electronic components frequently involve vibration (shake) testing.

Elevated vibration testing could introduce the potential of failure modes that are not representative of in-service failures. This is a common complaint of all mechanical tests. There is no recognized model for mechanical degradation testing. Thus, reliability testing of mechanical components or units is usually limited to conditions that represent the outer limits of the in-service conditions.

Sometimes the reliability engineer will test mechanically at levels above the expected service and specification conditions to identify the weakest components in an assembly. Elimination or strengthening of weaker components will improve the overall reliability of the system. However, data from this kind of test is not useful in determining the reliability of the unit. Degradation testing is described in more detail later in this *Primer* Section.

Types and Applications of Testing (Continued)

Truncation Tests

Truncated reliability tests are the most common type of planned test. Tests may be truncated in time, or number of failures. For instance, a reliability test could be planned and performed where the test will continue until 10 failures are observed. Or, the reliability test might be conducted until 5,000 hours are accumulated. In both cases, the time length or number of failures is identified to generate the MTTF with either one-sided or two-sided confidence intervals.

Truncated tests are performed to assure that sufficient data points are obtained to provide accurate statistical inference for this calculation. A typical result might be that the MTTF is 145 hours, with a 95% confidence that the actual mean is between 100 and 300 hours.

Truncated testing may be conducted with replacement or non-replacement of the failed units. Truncation failure and time examples are presented later in this *Primer* Section.

Human Factors During Reliability Testing

Various reliability authors describe problems associated with human factors in the area of reliability testing. Dodson (1995)[7] references MIL-STD-1472 (1999)[31], and MIL-HDBK-759 (1995)[25]. In the reliability testing of products, the human element is present and must be accounted for. Some of the initial considerations involve:

1. **Sight capabilities: What is the normal line of sight? Critical functions and indicators should be located within 15° of the line of sight. Color perception and color blindness may also be of concern.**

2. **Touch capabilities: The sense of touch or kinesthetic nature may be critical in testing. The placement of on/off controls in an instrument panel should be consistent between panels. "On" is always "up". Consistency in the use of similar size knobs or controls for the "on" function is necessary. Similar shaped control knobs are important. If colors are used for coding, the colors should be consistent in usage. Labels and labeling must also be consistent.**

Human Factors During Reliability Testing (Continued)

3. **Audio capabilities: The audio information should be simple. If the information is critical, redundancy or confirmation might be desirable.**

4. **Human thermal tolerance capabilities:**

   Heating: a minimum temperature of 20°C (68°F) is desirable
   Ventilation: a minimum of 0.85m^3 (30 ft^3) of air per minute
   Air conditioning: temperatures should be below 29.5°C (85°F)
   Humidity: about 45% relative humidity at 21°C (70°F).

5. **Human vibration capabilities: This could come from equipment or building vibrations. Motion sickness could be a problem also. (Dodson, 1995)[7]**

Ireson (1996)[12] mentions that testing falls into 2 categories: developmental testing and acceptance testing. Developmental testing checks to verify the effectiveness of design for use by people. Acceptance testing is performed by the customer to identify deficiencies in design. Candidates for human design testing should not be too familiar with the product, since excessive knowledge or skill can skew the test results. Testing should be performed early in the design phase of the project. The use of full-scale mockups or scale models are useful devices to examine adequacy of the design. These tests can perform four purposes:

1. **Determine if the product conforms to human factors design criteria**
2. **Confirm compliance with specific performance requirements**
3. **Obtain data on person-machine characteristics**
4. **Determine whether other variables were introduced through the design**

Test parameters should be defined for:

- **Condition of the test**
- **Resources used**
- **Apparatus or equipment**
- **Test equipment, tooling, and supplies**
- **Time and duration**
- **Personnel selection**
- **Test conditions**
- **Test materials**
- **Analysis of test data**
- **Reporting of test data**

VII. RELIABILITY TESTING QUESTIONS

7.1. Environmental stress screening has shown to be very effective in a production process. The levels of defects have dropped from 5% to 25 ppm. This would indicate:

a. ESS can be eliminated, it is no longer necessary
b. ESS is still needed, but change the applied stresses
c. All causes of defects have been found
d. Continue the present ESS techniques

7.2. An accelerated life test is performed on a new electronic device. The accelerated test is conducted at 150 °C, with a mean failure time of the devices equaling 100 hours. Given an activation energy of 0.25 eV, an acceleration factor of 2.0, determine the normal operating temperature in °C.

a. 111 c. 150
b. 384 d. 75

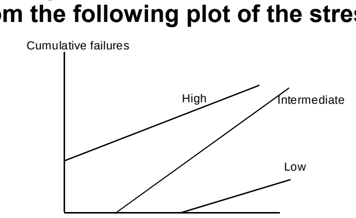
7.3. Salt cabinet tests, where coated materials are subjected to salt spray, is an example of:

a. Degradation testing
b. Truncation testing
c. Time to failure testing
d. Enhanced testing

7.4. The seeding of errors into a program and counting the number of seeded versus identified defects allows a test engineer to estimate the number of:

a. Defects in the program
b. Remaining defects
c. Errors left in the program
d. Seeded and unseeded errors

7.5. Accelerated life testing has been performed on a pro sports bicycle helmet. There were several levels of testing completed at low, intermediate, and high stress levels. What can be concluded from the following plot of the stresses?



a. Stress failure modes may not correspond to normal conditions
b. The plot is adequate for use
c. Useful failure modes are being uncovered
d. Nothing can be concluded; many more tests are necessary

7.6. A number of test units underwent accelerated life testing. There were three levels of stress testing conducted. The stress levels are given in multiples of the normal level. That is, the highest stress level was 10 times normal. Refer to the following data:

Stress	Life/hours
3x	17
5x	15
10x	10

Determine the projected life of the device at normal operating conditions, using a data plot projection.

a. 10 c. 19
b. 18 d. 20

7.7. Product reliability acceptance testing (PRAT) uses at least 5 testing methods in the production phase. Which method requires that the equipment operate without failure for a specified time inside a specified window, e.g., 150 failure free hours in a 300 time span?

a. All-equipment product reliability acceptance test
b. Bayesian reliability testing
c. Minimum MTBF assurance test
d. Weibull reliability testing

7. 8. A company is conducting a probability ratio sequential test (PRST) with the following intercept lines:

Accept: -4.0 + 0.01 × t
Reject: +4.0 + 0.01 × t

The 10^{th} failure was observed at 1,200 hours. What decision does the company make about the test?

a. Stop the test and accept
b. Stop the test and reject
c. Continue the test
d. Need more information to make a decision

7.9. The Arrhenius model is a model used to convert the reliability results of high temperature testing to equivalent normal condition life. This model is used for:

a. Coated high temperature materials
b. Electronic components
c. Oxidation properties of galvanized steel
d. Long term rotating mechanical components

