# SEMATECH IRONMAN GUIDELINES

A PARTNERING FOR TOTAL QUALITY DOCUMENT

SEMATECH

# SEMATECH IRONMAN™ GUIDELINE

TECHNOLOGY TRANSFER #95113028A–GEN

# CONTENTS

# 1. INTRODUCTION

This document details key elements of the **I**mproving **R**eliability **O**f **N**ew **M**achine **A**t **N**ight (IRONMAN) methodology and provides a roadmap for a successful implementation of IRONMAN. IRONMAN is a form of Reliability Growth testing that was created by Motorola, Inc. engineers working in partnership with a semiconductor process equipment supplier. An actual case study of the use of IRONMAN methodology is provided in the Appendix.

As a result of implementing the IRONMAN, one can expect some significant benefits, including a reduction in investment cost through early detection of failures, lower warranty cost, and decreased time to market.

The IRONMAN methodology is designed to be used by equipment suppliers for semiconductor manufacturing development. These suppliers work with SEMATECH and its members to deliver to customers the most reliable equipment in the shortest time possible. IRONMAN also is used by equipment suppliers to improve existing equipment and help in the process of developing the next generation equipment at the lowest cost to meet customer reliability expectations. Typically at SEMATECH, these projects have been part of a joint development project. Although running an IRONMAN has been a joint project in the past, you as a supplier can execute an IRONMAN without any outside help, which will demonstrate the maturity of your process. A reliability demonstration test known as a Marathon test is usually run after an IRONMAN to demonstrate the reliability achieved by the equipment.

The IRONMAN name is analogous to the sports related ”ironman” concept, which requires the world’s best competitors in multiple disciplines to reach the winning goal in the shortest time possible. The methodology is founded upon principles of integrity and respect, specifically

- The shared ownership of the process and the results between the equipment supplier and the customer
- Assured confidentiality of results and disposition outcome
- Fair and accurate reporting and communication
- Actions driven first by goals, then by schedule

Executing the IRONMAN methodology involves progressing through three stages, as described below and shown in Figure 1:

1. Preparation stage
2. Improvement Cycle stage
    - Execution
    - Analysis
3. Completion / Review stage

The preparation stage involves establishing and committing to goals, creating a plan for performing the IRONMAN testing, and providing external inputs such as requirements and resources. The improvement

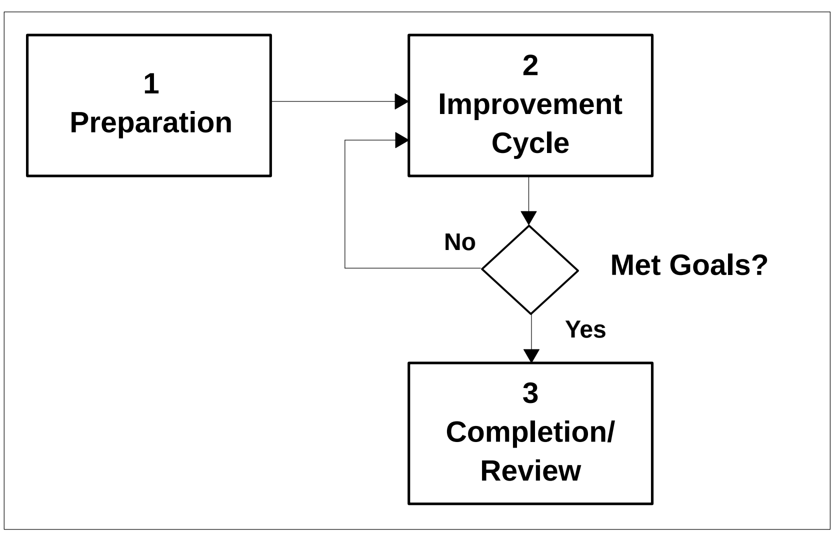



*Figure 1. Overview of IRONMAN Methodology*

cycle stage involves finding as many problems as possible in the time allotted, analyzing these problems to find root causes, and implementing the fixes. The completion and review stage involves determining if the goals of the IRONMAN have been successfully met during the time allotted, or if the project needs to be renegotiated. This process of reliability improvement is under the control of a Failure Review Board (FRB). The process is designed to ensure the successful development and deployment of the supplier's equipment to meet the customer's reliability requirements.

IRONMAN testing enables you to deliver a product to your customer with a lower failure rate due to the removal of early failures, as seen in Figure 2. The lower failure rate translates into a savings for you and your customers. The actual reliability performance is established in the Marathon testing that follows the IRONMAN. The measurements gathered are according to SEMATECH SEMI E-10 Standards.[1]

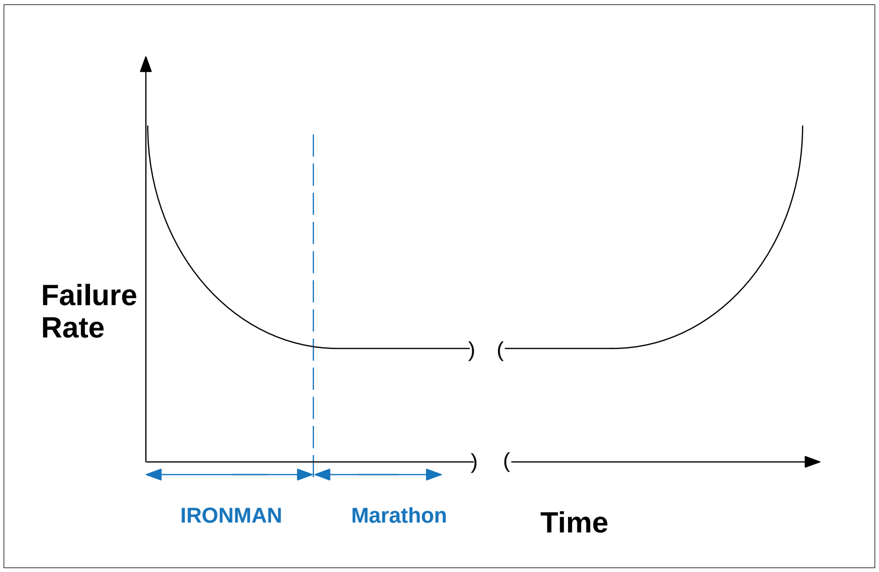



*Figure 2. Reliability Life Cycle*

[1] Contact SEMI for copy of *SEMI E-10-96 Standard for Definition and Measurement of Equipment Reliability, Availability, and Maintainability*

# 2. OVERVIEW OF METHODOLOGY

## 2.1 Background

Created by Motorola engineers working in partnership with a semiconductor process equipment supplier, the IRONMAN methodology is a form of Reliability Growth testing designed to improve equipment reliability and solve problems that occur during testing. The name reflects the process which typically involves cycling the equipment at night and leaving the daytime for completion of engineering work on hardware, software, or process development. The efficiency of this approach is measured by how quickly improvements can be made in mean time between failures (MTBF) of the equipment, repair time, and length of time to restore the customer's operation. Evolving from the original concept, IRONMAN has become effective in increasing the performance and reliability of the equipment.

## 2.2 Benefits

IRONMAN 's *Reliability Growth testing* results in equipment with less downtime and increased capabilities than would have been achieved had the testing not been performed. Although equipment complexity and diversity, as well as organizational differences, require that the methodology be tailored for individual companies, IRONMAN is based on the concept of partnership between equipment supplier and user and is driven by an agreed-upon schedule for accurate and fair communication among all parties.

Following are some of the benefits of the IRONMAN for both the equipment supplier and user community:

- Delivery of equipment with consistent quality to customer

- Reduced investment cost through early detection of failures
- Increased customer satisfaction
- Decreased overall investment
- Lower warranty cost
- Significantly lowered field service costs
- Enhanced market share through customer partnership
- Improved customer relations through common goals and better communications
- Improved reliability in planning and design for next generation
- Decreased time to market
- Improved cycles of learning through marathon testing and analysis

## 2.3 Requirements

In order to have a successful IRONMAN, you need a number of essential elements and resources. Your full management support is vital. The methodology also requires a cross-functional team effort of technically competent people dedicated to making IRONMAN work. You must provide a project manager who can plan the project, identify the resources needed, and implement the methodology such that reliability concerns from the user's perspective are identified. This improves your chances for first-time test success and repeatable results, which pays dividends on all projects that follow.

You must provide the necessary resources if successful execution is to be achieved. These resources include personnel with the appropriate skills, proper equipment, and a realistic schedule. Required skills include project management, cross-functional team building, training on the equipment, communications and debriefing of equipment. In addition to the project manager, other team members include the reliability manager and the following engineering functions: reliability, test, quality assurance, manufacturing, design, and software. Also included are operators and technicians who need to be trained in their roles. The people assigned to the program should not have any work assignments or outside obligations that conflict with running the IRONMAN. A summary of the supplier resources required is listed in Table 1. To help increase the efficiency of your team, SEMATECH has developed software to facilitate the IRONMAN process. See Section 4 for more detailed information.

*Table 1. Supplier Resources*

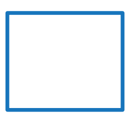
| **Title** | **Function** |
|---|---|
| Engineering (Design) | Software, electrical, mechanical, material |
| Maintenance | Service equipment |
| Manufacturing | Perform process related assembly |
| Operators | Operate equipment, start each run of the IRONMAN tool |
| Project Manager | Oversee IRONMAN project |
| Quality Assurance | Verification of suppliers and parts<br>Verification that processes are being executed correctly<br>Provide feedback on improving processes |
| Reliability Manager | FRB Leader |
| Reliability Engineer | Data analysis and planning of tests |
| Safety | Define and document safety policy and ensure equipment safety |
| Test | Determine that equipment requirements are testable<br>Ensure sufficient information exists to develop test plan<br>Ensure test coverage for requirements according to operational profile |

When the user participates in the IRONMAN as a partner, the user provides a co-project manager to oversee it from the user’s perspective. The role requires project management and communication skills, competence in the technology area, and IRONMAN expertise. The project manager should bring equipment engineers, process engineers, and reliability experts as needed to ensure project success.

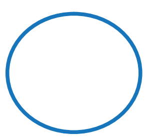
## *2.4 Methodology Representation*

IRONMAN is a dynamic process that addresses the key steps for management in implementing the methodology. It delivers the efficient achievement of reliability goals that enables an equipment supplier to provide customers with quality equipment that meets their goals. There are three stages to this process with defined deliverables in the form of documentation or resources that must be provided to the next stage or state within a stage. In this document, the IRONMAN process will be represented by a network called a Rainbow Net[2]. Rainbow Nets are object-oriented networks that facilitate the modeling and simulation of system behavior. Rainbow Nets have the following basic elements:

**Symbols** **Definitions**



A square represents some state where the indicated activity to create a deliverable takes place or a "place" where a deliverable comes from.



A circle or ellipse represents a deliverable that is created in one process state and is required in order to reach the next state or stage in the process.

[2] A. Johnson, M. Schoenfelder, and D. Lebold, "Modeling Maintenance-strategies with Rainbow Nets," *Proc of the 1992 Annual Reliability and Maintainability Symposium*, Las Vegas, pp. 449–455.

A bar represents the activity required (that takes time to complete) to develop the deliverable for use in the next process state. There may be multiple activities going on at once.

An arrow shows where the deliverable is going when the action or activity is complete.

# 3. IRONMAN METHODOLOGY

IRONMAN is a three-stage process where each stage consists of one or more states that represent activities being executed in parallel and / or in sequence. Concerns about growing reliability to an acceptable level typically begin at an equipment's planning and design phase and continue throughout all life cycle phases (see Table 2). The IRONMAN, which should start at the prototype phase, continues the reliability focus. Key resources for IRONMAN Reliability Growth testing include trained people, time for off-shift operation, supplier engineering support, and material (i.e., wafers, packages, etc.) for cycling through the equipment. Furthermore, software packages for failure tracking and analysis such as the SEMATECH Failure Reporting, Analysis and Corrective Action System Database Management System (FRACAS DBMS) and Test Data Collection (TESTDAC) are extremely helpful.

*Table 2. Reliability Engineering Activities by Life Cycle Phase*

| **Concept and Feasibility Phase** | **Design Phase** | **Prototype Phase (Alpha Site)** | **Pilot Production Phase (Beta Site)** | **Production Phase** | **Phase Out Phase** |
|---|---|---|---|---|---|
| Goal Setting | Design-In Reliability | System Test | FRACAS | FRACAS | FRACAS |
| Apportionment | Modeling | Rel. Level Assessment | System Test | Rel. Level Assessment | Transfer Rel. Knowledge |
| Prelim CoO Calculations | FMEA / FTA | Design Review | Rel. Level Assessment | Validate Modeling | |
| Design Review | Part Life Test | FRACAS | CoO Calculations | | |
| | Design Review | CoO Calculations | IRONMAN / Marathon | | |
| | CoO Calculations | IRONMAN / Marathon | | | |
| | Strife Test | | | | |

The IRONMAN calls for using appropriate Reliability Growth testing procedures to meet the reliability improvement goals and objectives of the supplied equipment configuration. Through this testing, outcomes are identified, analyzed, and controlled. Corrective actions are implemented through a continuously iterated testing cycle until reliability goals are met. The time required to achieve reliability goals is reduced by orders of magnitude by increasing the rate of Reliability Growth.

IRONMAN also is described as the equipment reliability improvement stage of the SEMATECH Qualification Plan Guidelines for Engineering[3]. Before implementing IRONMAN, the reliability baseline should be established. The closer this demonstration shows the equipment is to meeting the reliability goals, the shorter your IRONMAN testing will be. If, for example, a significant percentage of the defects found during IRONMAN are software defects, this indicates that more emphasis should be put on removing software defects during the design phase. Software should be thoroughly tested prior to IRONMAN. Otherwise, software testing will be your IRONMAN.

## *3.1 Preparation Stage*

The IRONMAN must be managed properly for success. This involves the execution of a management process that is divided into three stages, (preparation, improvement cycle, and completion) consisting of several states, as represented in the Rainbow Net in Figure 3. The initial states are the setting of goals and objectives, development of the Reliability Growth plan, gathering of resources, and defining the baseline configuration of the equipment. Several actions must take place to

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[3] Contact SEMATECH for a copy of the SEMATECH *Qualification Plan Guidelines for Engineering,* Technology Transfer #92061182B–GEN.

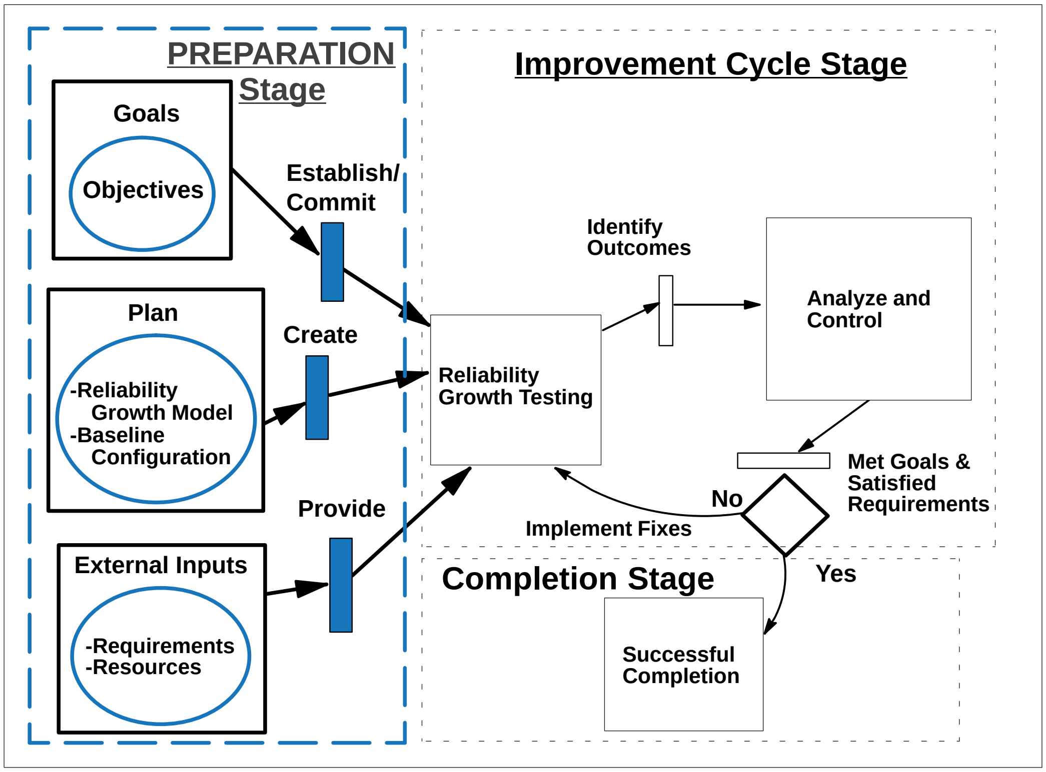


*Figure 3. Preparation Stage of IRONMAN*

develop deliverables in one state of the IRONMAN that are required for the activation of other states.

In the preparation stage, the first action is to establish and commit to the goals and objectives that are deliverables to the rest of the process. Objectives should include duration of testing, number of problems to be found, and cycle of learning improvement to be achieved. Also, the percentage of problems that must be fixed should be established (minimum of 80%). This goal-setting action launches several other preparatory actions, including creation of a Reliability Growth plan and a baseline configuration to be used for IRONMAN testing (see Figure 4).

Requirements and resources also must be defined and provided. These are needed not only for the execution of IRONMAN, but they also affect

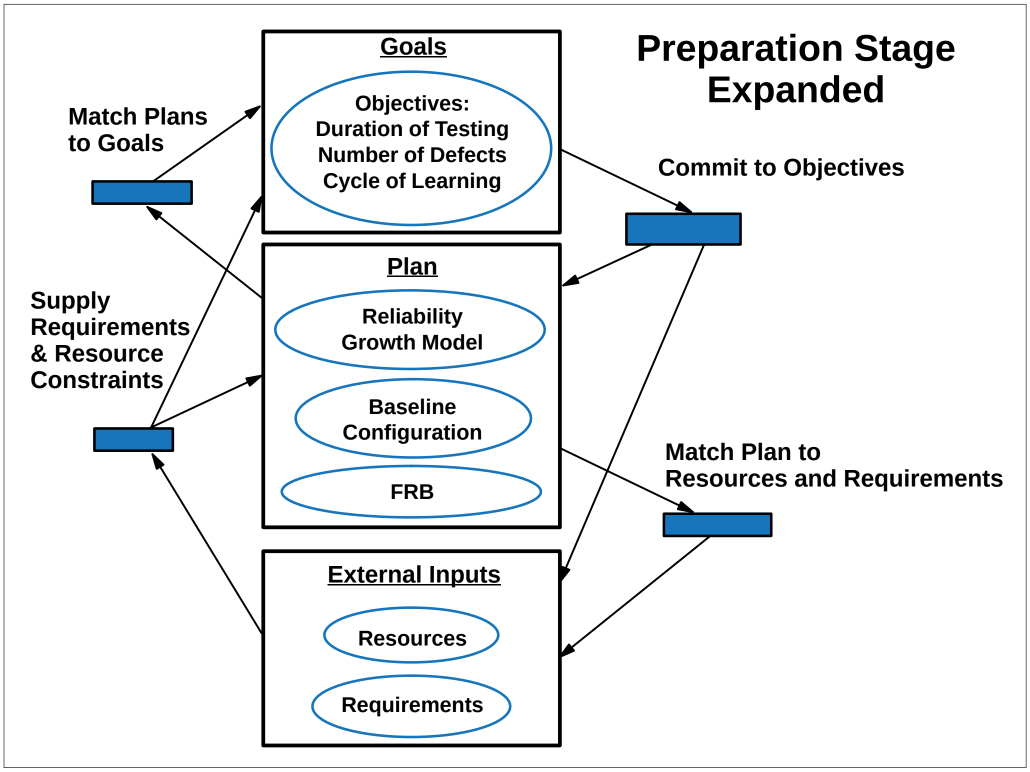


*Figure 4. Preparation Stage Expanded*

the goals and objectives and consequently the plan. The resources include people with the right skills, proper equipment, adequate financing, and realistic schedule. See Section 2.3.

The preparation stage can be expanded from Figure 3 and treated as a self-contained process, as shown in Figure 4. Preparation is viewed as an iterative process where there is interaction among setting goals, planning, and providing resources and requirements, which approximates what actually goes on in an organization. This allows many of the key inputs (e.g., the goals, objectives, plans and requirements) to be improved and fine-tuned. A verification process must take place through two actions: matching plans to goals, and matching plans to resources and requirements. Embedded in these actions is the evaluation of the Cost of Ownership (CoO) using the

SEMATECH Cost of Ownership model[4]. These actions provide improved and refined deliverables to the next stage, the improvement cycle stage that starts the execution of the Reliability Growth testing. The baseline configuration should be provided, along with an estimate of the initial reliability level for that configuration.

Another essential part of planning that should be established is the Failure Review Board (FRB)[5]. The FRB reviews failure trends, facilitates and manages the failure analysis, and ensures closure on failures and assigns owners of problems. Even after the initiation of the improvement cycle stage, IRONMAN allows for the possibility of unforeseen events causing a modification to one or more of the deliverables from the preparation stage. Such modifications must be approved by both parties.

Calculating CoO is an important procedure for management to use in making decisions about which reliability improvements to make. For each phase of the Reliability Engineering Activities during the equipment's life cycle, you, as equipment supplier's management must make a risk assessment that includes determining the cost of reliability improvement. You should use the SEMATECH CoO model through the first four phases of the equipment's life cycle (see Table 2). CoO calculations are started during the first phase. The equipment manufacturer's cost of reliability is shown in Table 3.

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[4] Contact Wright, Williams, and Kelly, 11875 Dublin Blvd. Suite D262, Dublin, CA 94568 for the TWO COOL software.

[5] For a more detailed description of the FRB process, obtain a copy *of Failure Reporting, Analysis and Corrective Action System:* Technology Transfer #94042332A–GEN.

*Table 3. Manufacturer's Cost of Reliability*

| Costs of... | Cost Factors |
|---|---|
| Prevention | Customer requirements, designing-in reliability, design reviews, FMEA, FTA, parts program, and supplier qualification |
| Appraisal | Testing, failure reporting, modeling |
| Internal Failures | Yield loss, redesign, manufacturing equipment down time |
| External Failures | Warranty cost, field support cost, loss of goodwill |

Appropriate decisions can minimize the Life Cycle Cost (LCC) and CoO and the differences between them. The level of reliability and how it is achieved have a direct impact on LCC and CoO. Achieving higher reliability is a balance of higher acquisition cost versus lower field failure cost and lower scrap cost. It is also possible that selective design choices can both increase reliability and lower acquisition cost if they are made early in the life cycle of the equipment. This relationship between LCC, IRONMAN testing, and key early design decisions that determine the designed-in reliability is shown in Figure 5.

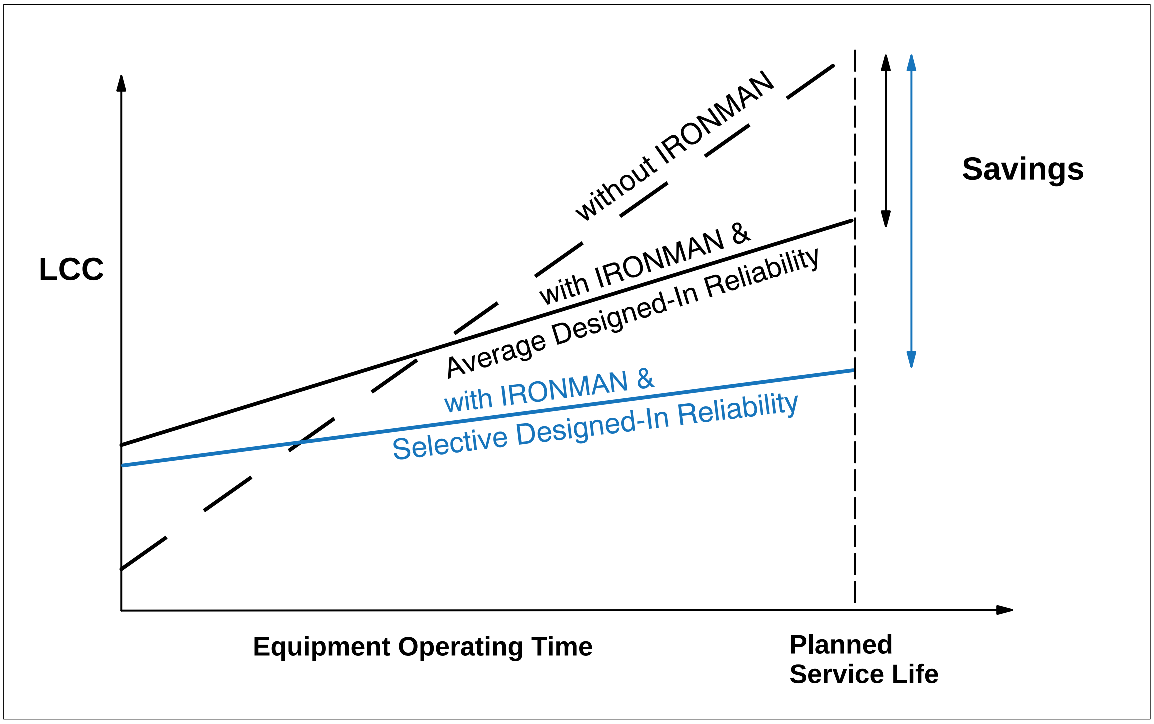


*Figure 5. Impact of IRONMAN Testing and Designed-In Reliability*

The investment in IRONMAN testing and Designed in Reliability continues to pay dividends over the entire life cycle of the equipment. Typically, the reliability level for the minimum LCC cost is the optimum reliability level. Further reliability improvement beyond this level will reflect a negative return on investment. LCC and CoO are calculated using the following equations:

LCC = Acquisition cost + cost of field failures + cost of preventive maintenance + cost of spare part inventory + cost of scrap

CoO = LCC + operating cost + consumable cost + utilities cost + facility cost + interest cost + waste disposal cost + training cost + other support services

## 3.2 Improvement Cycle Stage

The improvement cycle stage, shown in Figure 6, involves two states: the execution state where the Reliability Growth testing process occurs, and the analysis state where analysis and control of the IRONMAN occurs. The *execute* and *analysis* states are cycled until the goals of the Reliability Growth testing are met. The objective is to get IRONMAN set up in the supplier's facility, ensure that all the necessary resources are in place to perform all the steps, make the process for conducting the passive and active cycle debug operational, and gather the required metrics for each cycle. The passive cycle debug is the step of the IRONMAN that attempts to fix those problems that occur from handling materials. This step stresses the material-handling components of the equipment without the complexity of handling material. The active cycle debug step stresses the material handling and closely simulates the actual process. The focus in these steps should be on executing tests that will shake down the high failure subsystems and components that most affect the equipment's reliability. This should help ensure the most rapid Reliability Growth possible.

In the Analyze and Control state, the data are evaluated daily to determine root causes and establish corrective actions needed to resolve the problems per the FRB guidelines. Reports are generated on a weekly basis to indicate the progress. You start to gather data on the length of the cycle of learning (see Section 3.2.1) and record the frequency analysis data (see Section 3.2.2). FRACAS software should be used to facilitate this process. An interface between TESTDAC and FRACAS is available for this purpose. FRACAS and TESTDAC are discussed in Section 4.

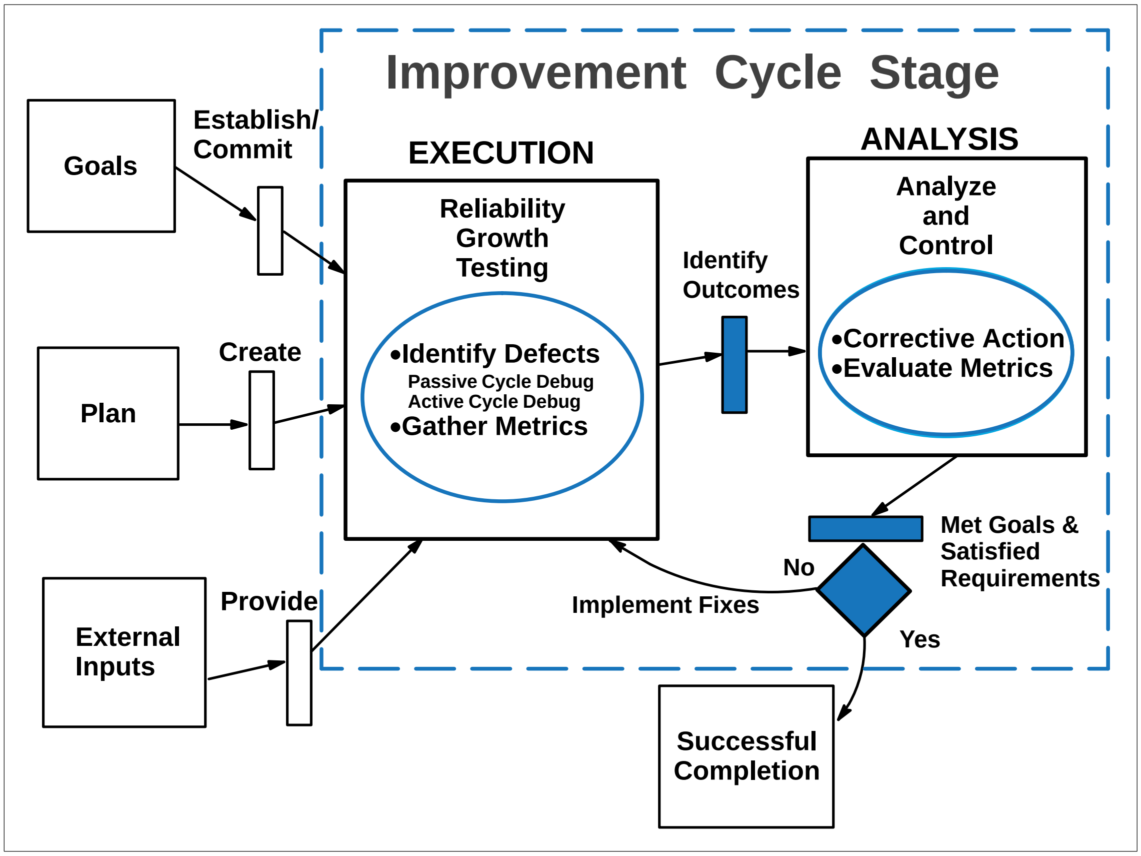


*Figure 6. Improvement Cycle Stage*

Based on the equipment's baseline configuration, appropriate testing procedures are modeled for Reliability Growth to meet the goals and objectives for reliability improvement. The primary reliability parameters are mean time between failure ($MTBF_P$), mean time to repair (MTTR), and mean units between interrupt (MUBI). Units can be wafers, cycles, packages, or other material. The Reliability Growth rate is plotted to demonstrate the rate of progress (see Section 3.4 for a more in-depth discussion of Reliability Growth modeling). Through this testing, the outcomes are identified, analyzed, and controlled. A tool such as the SEMATECH Tactical Software Reliability[6] may be helpful in analyzing

[6] Contact SEMATECH for a copy of *Tactical Software Reliability*, Technology Transfer #995092967A-GEN.

software problems. Corrective actions are implemented through continually iterated testing cycles until the reliability goals are met. To successfully execute this cycle, specific people and testing skills are required. The individual skills are not unique to this methodology but have been applied successfully with the IRONMAN methodology by equipment manufacturers.

### 3.2.1 Cycle of Learning

Critical to the success of the IRONMAN is the improvement (reduction of time to complete) in the cycle of learning process. The Cycle of Learning is defined as the execution of four steps, as shown in Table 4. Your objective is to shorten the time it takes to go from step 1 to step 4 by making improvements in this process. This cycle will become shorter as your team becomes more familiar with the equipment in a failed state and with the process used to find the root cause and fix the problem.

*Table 4. Cycle of Learning*

| Actions | Who performs |
|---|---|
| 1. Find the problem | Operators, service personnel, engineering |
| 2. Fix the problem | Data engineering, reliability engineering |
| 3. Document fix in ECN (configuration management) | Supplier, sub-tier supplier engineering |
| 4. Make fix available commercially | Supplier, sub-tier supplier |

The profile of your cycles of learning over the time for the IRONMAN test should look similar to Figure 7 in that you should experience a significant reduction in the time to complete a cycle as the testing progresses. Finding a problem is more than just having a test fail: it is finding the root cause. Fixing the problem is more than finding a solution that will pass the test that failed, but finding a corrective action that will not break any other function and withstand a rigorous test.

Increasing the rate of Reliability Growth requires improving the Cycle of Learning. The sooner a defect in the design or deficiency in a manufacturing process is uncovered and corrected, the shorter the time it takes to get the product into production, and the higher the quality. Decreasing the Cycle of Learning means increasing the opportunities to gain knowledge about the system deficiencies and following up with a corrective action in the limited time available for testing. It also means minimizing the confusion about the equipment and the processes by maintaining tight configuration management control.

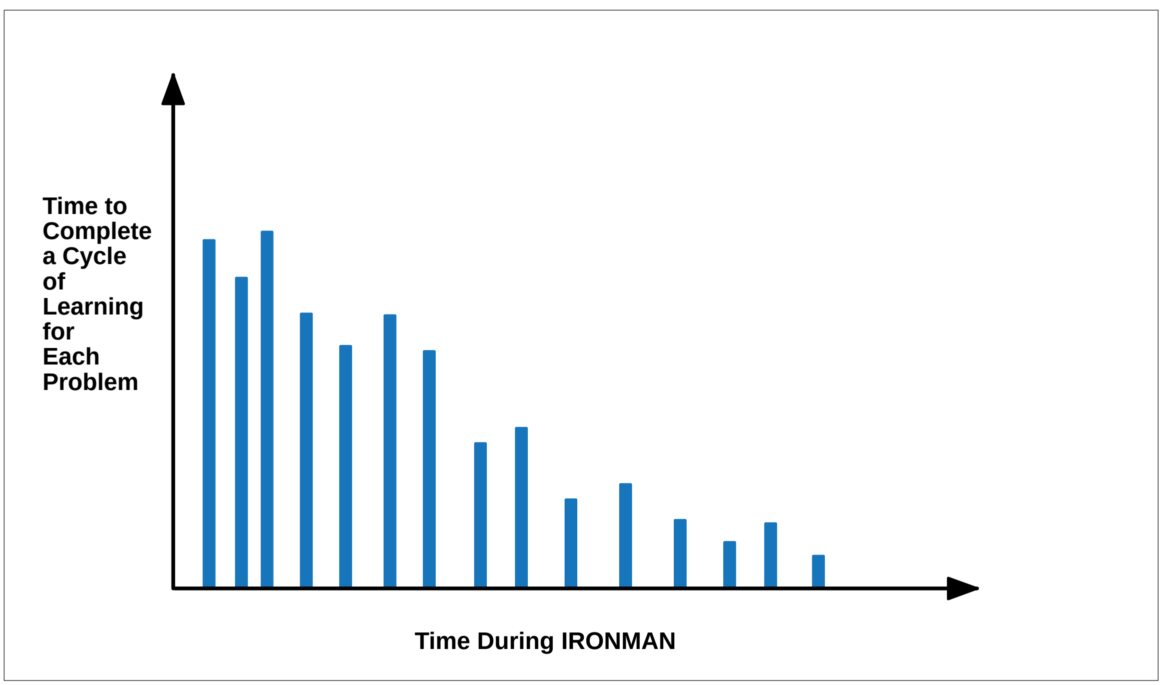


*Figure 7. Improving Cycle of Learning During Testing*

### 3.2.2 Frequency Analysis

To make the best possible decisions, many different views of data with respect to time are important. Frequency analysis is the application of statistical methods to visually represent equipment reliability information taken over time. In this method, the number of new problems found are plotted by week of occurrence. The key is to support timely decisions so that the window of opportunity for making the right decision is not lost.

One important parameter to graph that is an indication of the improvement in reliability is the frequency of finding problems. At the beginning of the test, lots of problems should be found. As time progresses in the test, it should be harder for you to find problems in the equipment, even with your most vigorous efforts to break it. This will be reflected by a graph of failures per week versus calendar time during the IRONMAN. This frequency should be decreasing with time as shown in Figure 8. If this frequency is not decreasing, it may be an indication of serious design problems. If this frequency is lower than expected, it may be an indication that the testing is not rigorous enough.

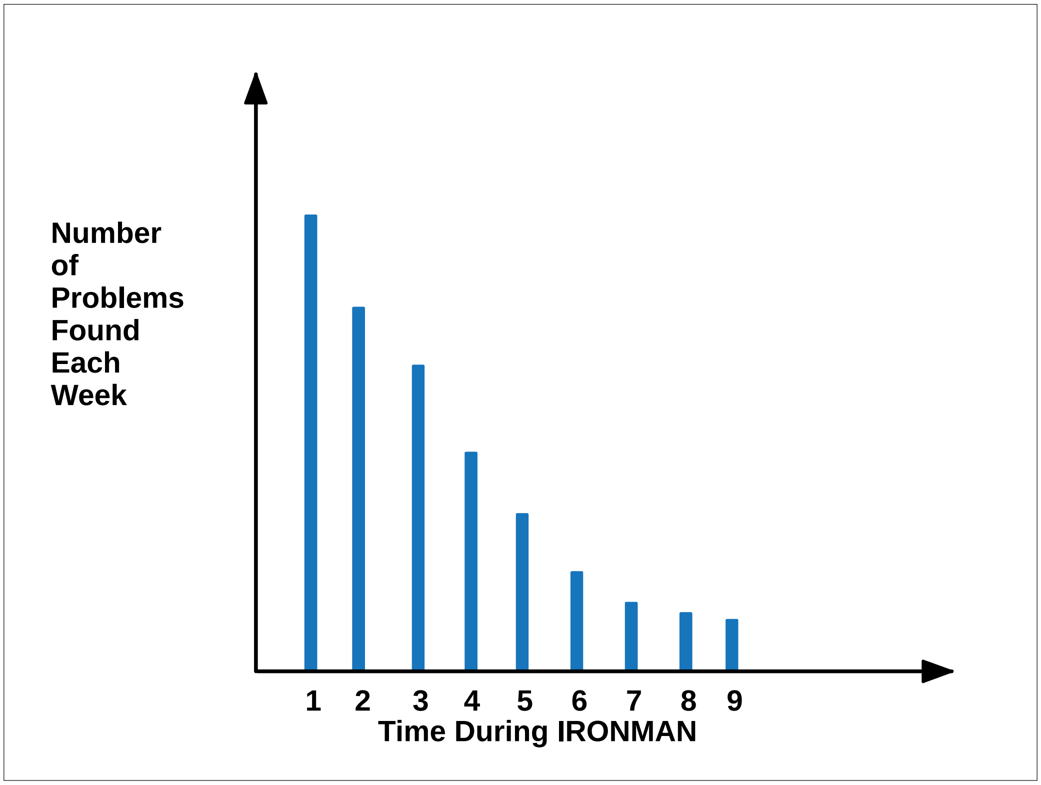


*Figure 8. Frequency Analysis of Problems Found*

## *3.3 Completion Review Stage*

Achievement of the predetermined goals, which includes satisfying the established requirements, signals that IRONMAN testing is complete as shown in the Analyze and Control state in the Rainbow Net in Figure 9. Successful completion leads to performing the Marathon test as the next step. If, at any time during the improvement cycle, it is determined that the Reliability Growth rate experienced is not adequate to achieve the goals in the Statement of Work (SOW) within the time allotted, then renegotiation of the project to address the issue of unattained reliability performance should be considered.

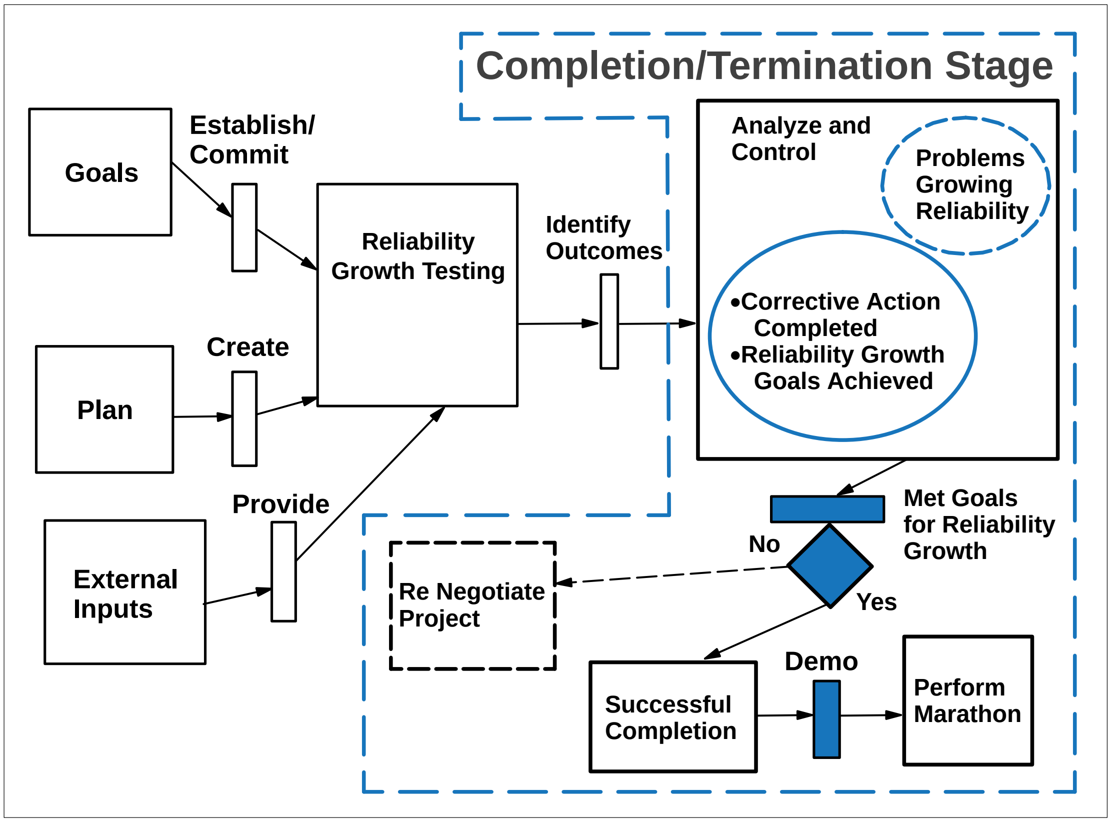


*Figure 9. Completion/Review Stage*

Performing Marathon testing after the IRONMAN is the appropriate way to measure reliability performance achieved and determine the maximum utilization possible for the given equipment downtime characteristics. The purpose of IRONMAN is to test, analyze, and fix problems, not measure reliability performance.

Within one month of the conclusion of the active IRONMAN, both supplier and user should meet with all IRONMAN participants for a final review. The agenda should be tailored to the specific equipment and application, with the following topics included:

- Accomplishments, including tools, procedures, and philosophy

- Brief review of open and closed items and agreement on how to track open action items
- Lessons learned and things to do differently
- Incorporation of IRONMAN methodology at the supplier's site
- Supplier's feedback
- Future opportunities for new and other existing equipment improvement

A brief report should be issued by the IRONMAN team to the equipment supplier and user.

## 3.4 Reliability Growth Modeling

Reliability Growth is a powerful method for measuring the increase in reliability of a product toward its design criteria. Reliability Growth is the improvement of equipment reliability by finding and removing design defects, misapplied parts, uncontrolled processes, and workmanship defects. The rate at which this is accomplished determines the rate of reliability growth. The rate at which Reliability Growth takes place depends on how rapidly defects are discovered, how fast corrective action can be identified and implemented, and how soon the impact of the change is reflected in the product delivered to the customer.

The Reliability Growth can be brought about by improvements in one or more of the following areas:

- Design
- Part selection and screening
- Familiarization and learning by participants

- Management team

Creating a design with the following characteristics and processes facilitates reliability growth:

- Design such that errors and problems are recognized easily
- Minimize complexity of the design
- Well disciplined configuration management process
- Efficient process of fixing problems and generating ECNs

There needs to be a set of ground rules for part selection and screening such as the following:

- Establish part criticality (Does part perform critical functions, have limited life, long procurement lead time?)
- Determine if there is a match of part with required function and expected operational environment
- Determine part availability
- Estimate expected part stress in its application
- Determine efficiency of screening or burn-in methods used for improving reliability

Familiarization and learning by participants comes about as they learn to perform required tasks faster and without error, which results in a reduction in the cycle of learning.  If the tasks to be performed have an established documented procedure that is easily understood, this facilitates reliability growth in the process.

Management can implement processes to improve the reliability throughout the life cycle of the product, not just during IRONMAN testing. By implementing effective reviews of the requirements, specifications, and design, management can achieve a significantly shorter testing phase of the prototype and product. By calculating the CoO, management can track the impact of reliability and maintainability improvements on the user, and make informed decisions on what to improve based on this assessment. Successful Reliability Growth begins at the planning and design phases of the equipment where management can implement design for testability guidelines.

One of the most widely used and straightforward Reliability Growth models is the Duane Model. The popularity of the Duane Model comes from the ability to plot Duane's Equation as a straight line on log-log paper. The equation can be stated as follows:

$$C(T) = KT^{\beta}$$

C(T) is the cumulative MTBF (you can also substitute metrics such as mean units per interrupt)

T is the time at which the function is being evaluated

K is the initial MTBF

$\beta$ is the growth factor

By taking the natural log of both sides, a linear equation results:

$$1n\ C(T) = 1n\ K + \beta\ 1n\ T$$

This equation produces a linear plot on log-log paper, such as the example shown in Figure 10. The slope of the line indicates the rate at which reliability is being grown. A slope between 0.3 and 0.6 indicates that an organized effort is being made to grow reliability. A slope of 0.1 or less indicates that no effort is made to grow reliability, or there are serious flaws in the design architecture that may require a redesign. In either case, immediate corrective action is required.

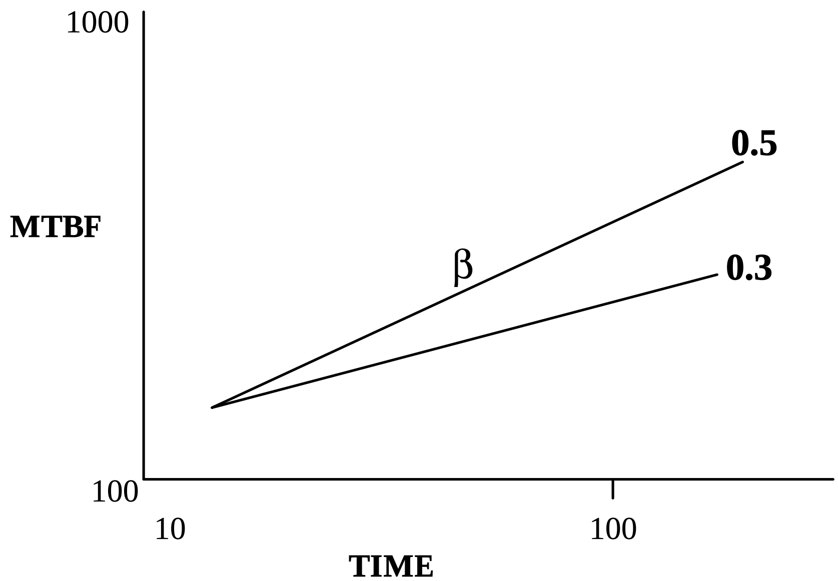


*Figure I0. Duane Plot*

As an example of a Duane plot of IRONMAN reliability improvement test data, consider a test run for 1500 hours with failures at the following operating hours: 5, 40, 43, 175, 389, 712, 795, 1299, and 1478.[7] This data is

[7] Taken from the section by Paul Tobias in *SEMATECH'S The Eighth Applied Reliability Tools Workshop,* in Boston on October 12–13, 1995.

shown in Table 5 and plotted in Figure 1 1. Using the U.S. Army Materials Systems Analysis Activity (AMSAA) model gives a value of 0.516 for β.

The method used to analyze the data should be carefully chosen. Because changes in the process of performing Reliability Growth can affect the rate of growth, piecewise regression may be appropriate. The IRONMAN team can consult several references, such as MIL–HDBK–189 for Reliability Growth management and MIL–HDBK–338.

*Table 5. Data for Duane Plot*

| Time of Failure | $MTBF_P$ | Cum ($MTBF_P$) |
|---|---|---|
| 5 | 5 | 5 |
| 40 | 35 | 20 |
| 43 | 3 | 14.3 |
| 175 | 132 | 43.75 |
| 389 | 214 | 77.8 |
| 712 | 323 | 118.67 |
| 747 | 35 | 106.7 |
| 795 | 48 | 99.4 |
| 1299 | 504 | 144.3 |
| 1478 | 179 | 147.8 |

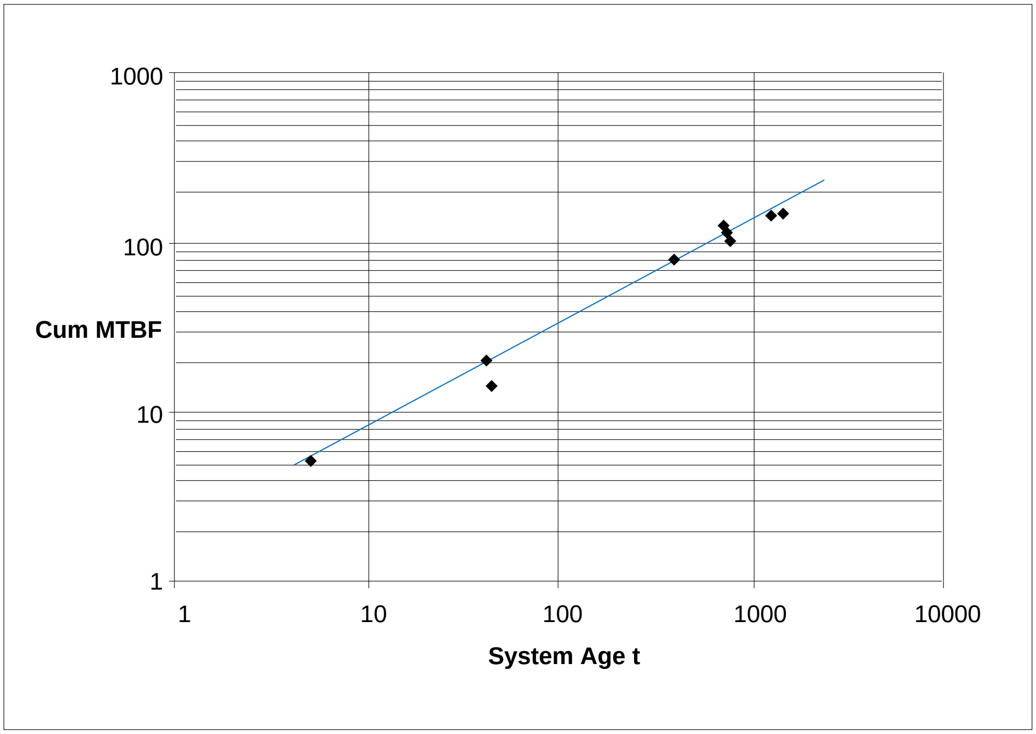


*Figure 11. Duane Plot of CUM MTBF vs System Age (time)*

# 4. SEMATECH APPLICATION SOFTWARE

## *4.1 SEMATECH FRACAS DBMS*

The SEMATECH FRACAS DBMS System facilitates failure reporting to establish a historical database of failure events, causes, failure analysis, and corrective actions. This accumulation of knowledge minimizes the recurrence of particular failure causes. The FRACAS DBMS itself is available from SEMATECH, or you can implement the same concept in whatever software you choose. The database is just a part of the overall FRACAS process. If you create your own software, the database should have the same software requirements and characteristics at both the supplier's and user's sites.

The FRACAS DBMS contains the following tables, which are more fully specified in the SEMATECH FRACAS document.

- **Configuration Table:** Contains basic machine data, such as serial number, location and life cycle phase.

- **Events Table:** Contains data about failure events, such as date, time, part number, assembly code, down time category and repair action.

- **Problems Table:** Contains data about problem resolution, such as assembly code, root cause, fault category, and resolution state.

SEMATECH FRACAS DBMS depends on accurate records of failures, their root causes, their corrective actions, and other reliability-related events.

## 4.2 TESTDAC

Test Data Collection (TESTDAC) software is used to facilitate the gathering of data about the state changes (i.e., events) of the supplier's equipment while the equipment is running the IRONMAN Reliability Growth Test or the Marathon Reliability Demonstration Test. In the event of failures, TESTDAC allows engineers to record corrective actions. Furthermore TESTDAC can generate reports and graphs depicting a variety of reliability statistics. TESTDAC should be installed on a computer near the equipment being tested so that operators may register the equipment's machine states, problems, and repair actions as they occur.

Besides reducing the amount of work required to log data, a computerized test log tool such as TESTDAC constrains the operators' entries to standardized categorizations of equipment state. Specific information is entered in predetermined data fields prompted on the screen. Therefore, the tool will enforce the definitions of failures, interruptions, assists and repairs. Time will be properly accounted, and only valid state changes will be logged. In this respect, all specific types of data are uniformly registered in the correct category in the database.

The TESTDAC application is intended to run along with FRACAS DBMS discussed in Section 4.1. Since TESTDAC uses the FRACAS database tables, FRACAS must be installed before TESTDAC. Furthermore, a description of the equipment under test must be configured into FRACAS before TESTDAC can be used to record test data. While running TESTDAC, any unscheduled or scheduled downtime events are automatically reported to SEMATECH FRACAS.

At the beginning of an IRONMAN reliability growth test, the test engineer will use the TESTDAC **New Setup** function to prepare for testing. Figure 12 shows the TESTDAC Test Setup screen. After selecting a test type, the operator can enter a test name, and serial number for the unit under test, select the number of processes and customize the process type. The setup also allows input of both batch size and lot size. Thus, a complete characterization of the system being tested, processes being used, and tests being performed is recorded.

The process type information is specifically for IRONMAN testing. Table 6 shows the default process types for the number of processes chosen.

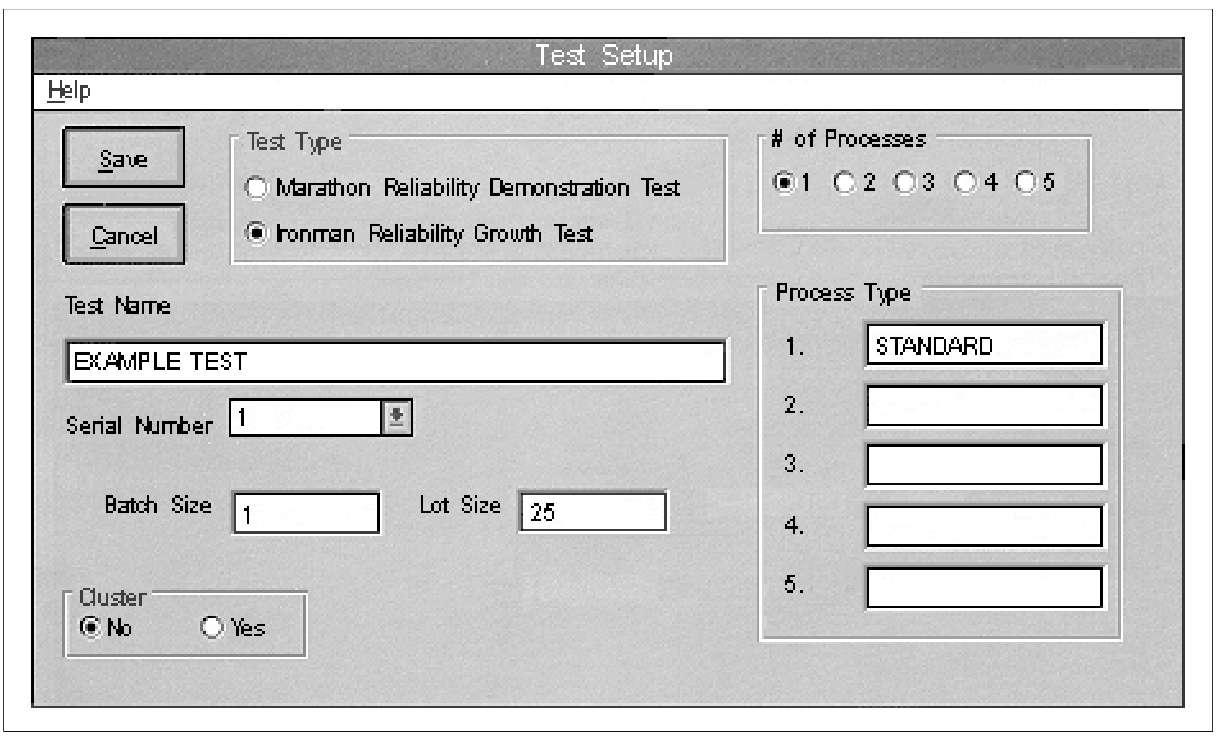


*Figure 12. TESTDAC Test Setup Screen*

*Table 6. TESTDAC Default Process Types*

| If the number of processes is: | The Default Process type(s) is (are): |
|---|---|
| 1 | Standard |
| 2 | Standard and Accelerated |
| 3 | Standard, Accelerated and Decelerated |
| 4 or 5 | These process types must be entered by the user |

Once the test is set up, the operator uses the **Open Test** command to prepare for the collection of data. The operator enters the Lot Id and selects the appropriate process. The batch and lot size fields start with default values, although they can be changed. **The Start Test** button is used to initiate the recording of test data. See Figure 13.

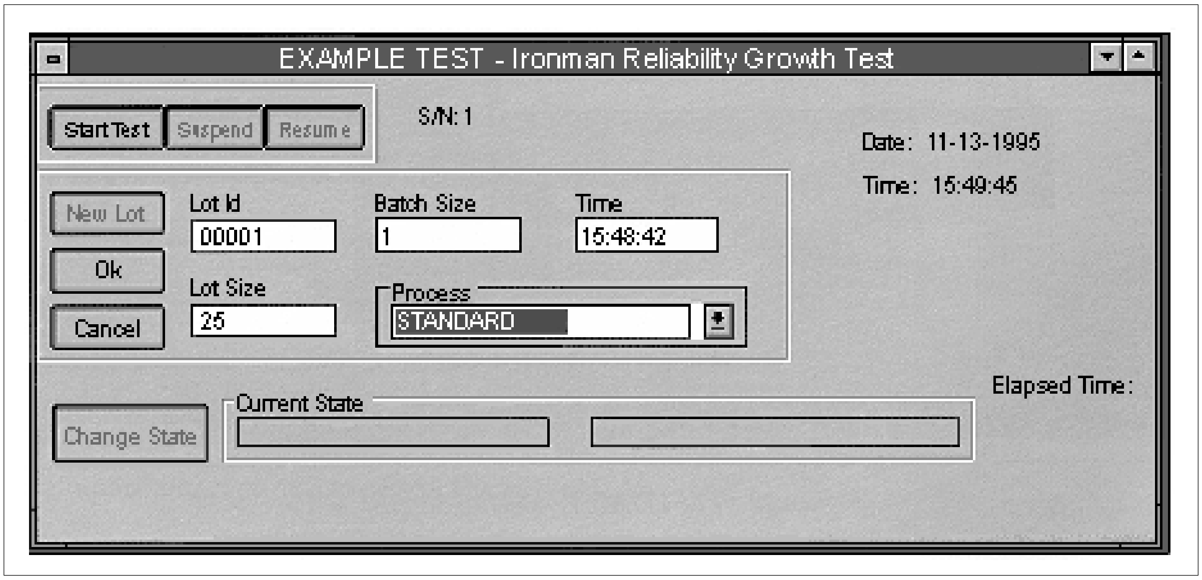


*Figure 13. Test Data Collection Screen*

The equipment under test can be in one of the uptime states, which are *Productive Time, Standby Time, Engineering Time;* one of the downtime states such as *Scheduled Downtime or Unscheduled_Downtime;* or in a *Non-Scheduled Time* state. Being able to account for *all* equipment time, both scheduled and non-scheduled, is an essential element of data collection. Figure 14 shows all of the categories in which equipment time may be allocated.

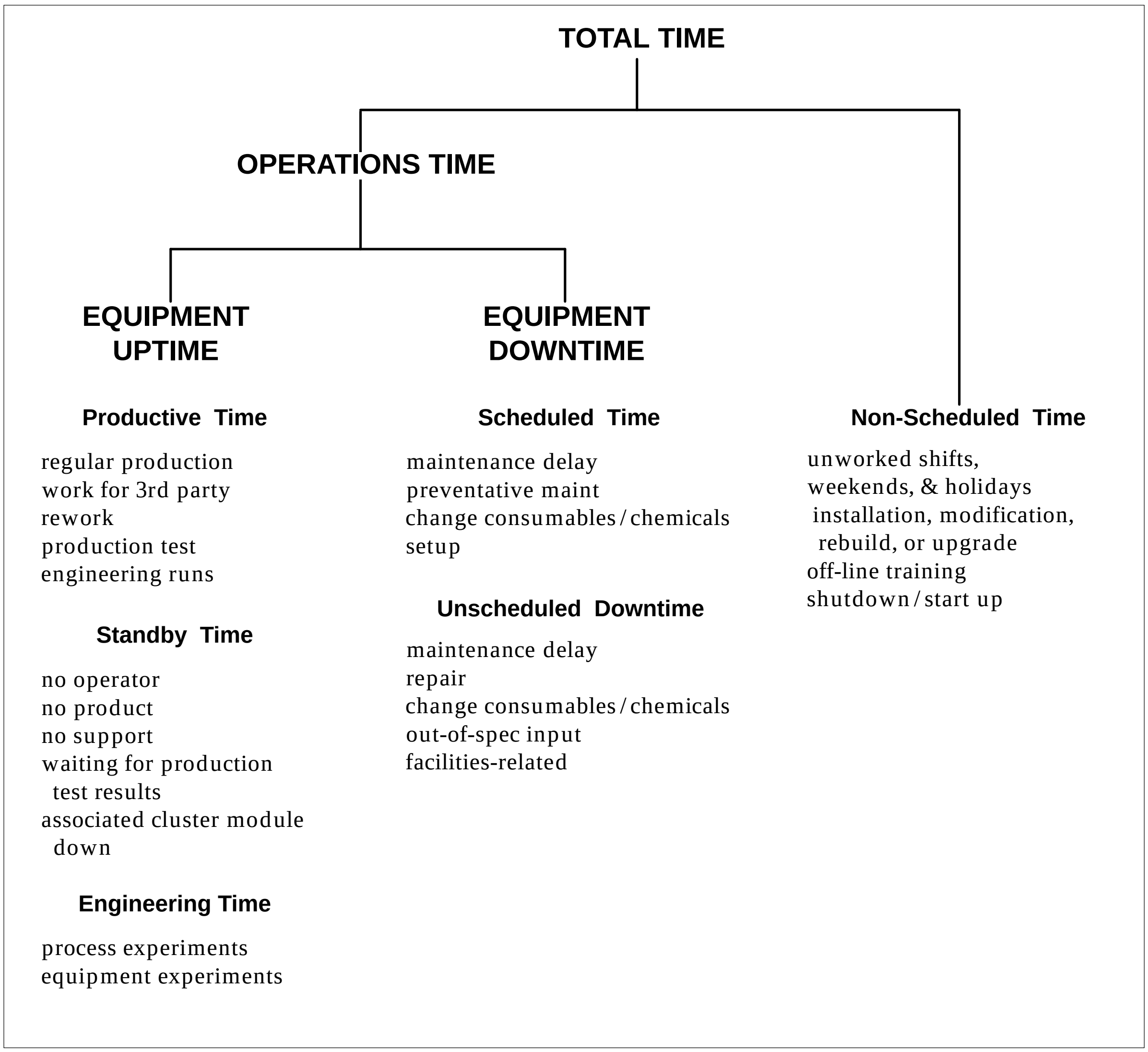


*Figure 14. Equipment Allocation of Time (from SEMI E10–92)*

From whatever state the equipment is currently in, TESTDAC allows the user to select a new state using the **Change State** button on the Test Data Collection Screen. TESTDAC records the time of every state change.

For example, at the start of a test, the equipment is assumed to begin in a *Productive Time* state. In the event of a failure, the operator presses the **Change State** button and a *Select New Tool State* dialog pops up asking for the next state. See Figure 15.

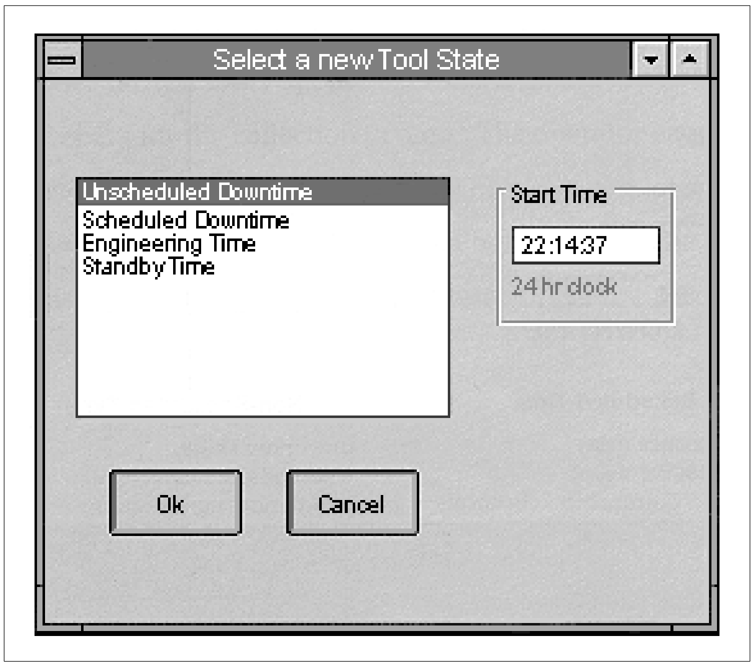


*Figure 15. Tool State Dialog*

Since a failure occurred, the operator should select *Unscheduled DownTime.* Pressing the **OK** button causes the Test Data Collection screen to add a text field prompting for a problem description. See Figure 16. Also, note that the time state has automatically been set to *Maintenance Delay.* When the **Change State** button is pressed again, the time state automatically changes to *Repair* and the Problem text field is replaced with a prompt for the Repair Action and Repair Engineer. A subsequent change in state pops up a dialog, giving the options of changing to *Maintenance Delay*, *Qualify*, or *Stand-by* time.

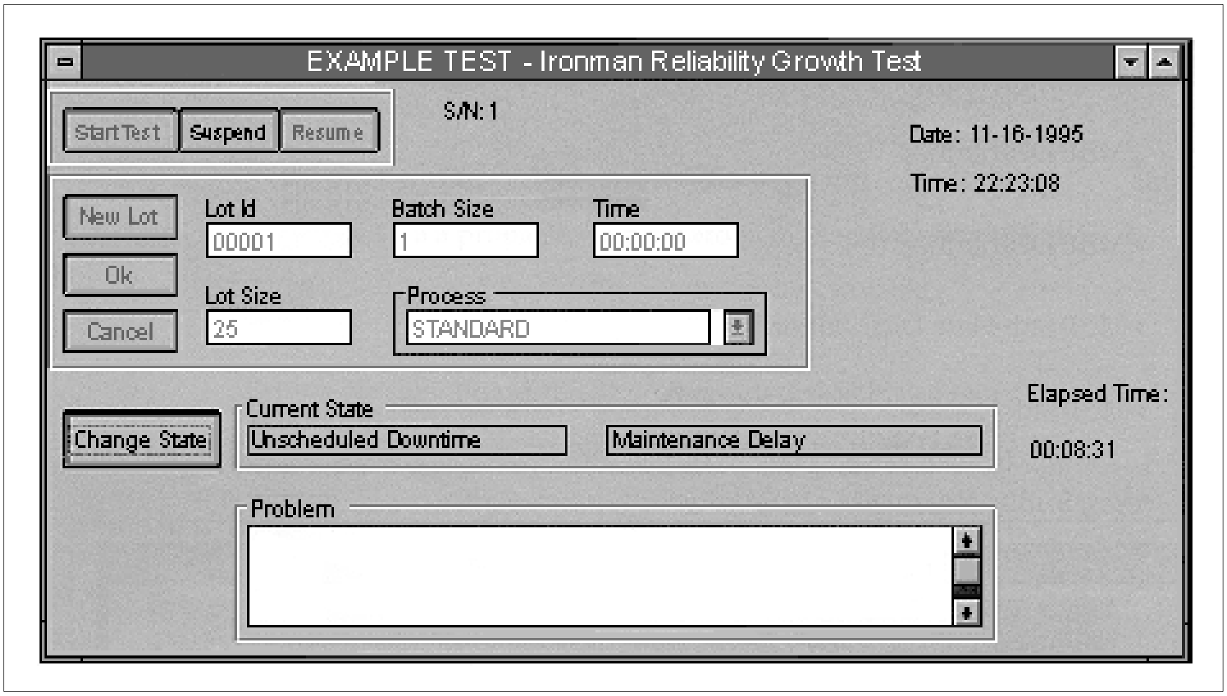


*Figure 16. Test Data Collection Screen with Problem Description*

Once testing has begun and a number of states have been recorded, TESTDAC allows editing of state change history via the *Test Log* screen. *The Test Log* screen is accessed through the **Edit** menu. This screen shows all the states that have been captured since the test began, except for the current state. Corrections can be made by editing the records.

Over time, it becomes important to run reports. All reports are by week, and it is recommended that reports be run and reviewed on a weekly basis. The reports also list cumulative data. The available report types include the following:

- MTBFp / MTTR

- MTOL / uptime / Utilization
- MWBI / MCBI
- MTBIp / MTBAp
- Equipment E10 Stackbar
- Test Log
- E10 Distribution (%)
- E10 Sub-State Distribution

Figure 17 shows an example report.

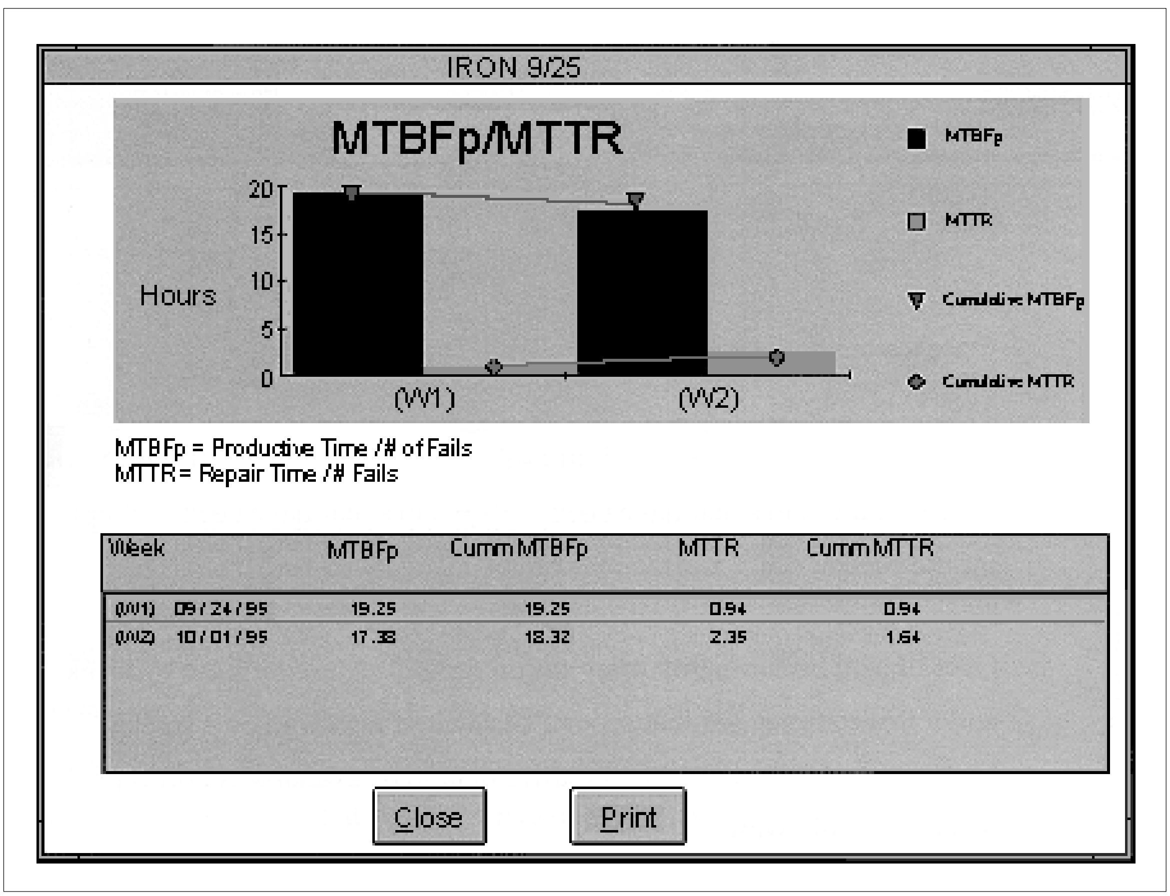


*Figure 17. Example TESTDAC Report*

# 5. GLOSSARY

**AMSAA Reliability Growth Model** The power relationship model developed by Crow and used by the U.S. Army Materials Systems Analysis Activity (AMSAA)

**Cycle of Learning** The time it takes to go through the steps of finding a problem, fixing a problem, documenting the fix, and making the fix commercially available

**Failure Review Board (FRB)** A group consisting of representatives from appropriate organizations with the level of responsibility and authority to assure that failure causes are identified and corrective actions are effected

**Life Cycle Cost (LCC)** Acquisition cost + cost of field failures + cost of preventive maintenance + cost of spare part inventory cost of scrap

**Marathon** A timed reliability test of equipment and process reliability and capability; it is a demonstration of reliability performance

**MCBI** Mean Cycles Between Interrupts = Number of cycles / number of interrupts

**$MTBA_P$** Mean (Productive) Time Between Assists = Productive Time / number of assists

**$MTBF_P$** Mean (Productive) Time Between Failure = productive time / # of failures that occur during productive time

**$MTBI_P$** Mean Productive Time Between interrupts = Productive Time / number of interrupts

**MTTR** Mean Time to Repair = total repair time / # of Failures

**MTOL** Mean Time Off Line = total equipment downtime / number of incidents

**MWBI** Mean Wafers Between Interrupts = Number of wafers / number of interrupts

**Operational Utilization** The percent of time the equipment is performing its intended function during a specified time period

**Reliability** The conditional probability at a given confidence level that the equipment will perform its intended functions satisfactorily or without failure, within the specified performance limits for a specified period of time

**Reliability Growth Testing** A form of testing that involves testing, analyzing the problem, and fixing the problem (TAAF) in order to improve the reliability of the equipment

**Root Cause** The reason for the primary and most fundamental failures, faults, or errors that have induced other failures and for which effective permanent corrective action can be implemented

**TESTDAC** **Test DA**ta **C**ollection is a menu-driven software program whose purpose is to collect data both in-house and from field experience, while running the Marathon Reliability Demonstration Test and IRONMAN Reliability Growth

**Utilization** Productive Time / Operational Time

**Uptime** Equipment Uptime / Operational Time

# 6. APPENDIX: CASE STUDY

The IRONMAN process is designed to achieve success for any process equipment in a development or manufacturing line. This includes equipment types used in diffusion, photolithography, CVD, ion-implantation, chemical etch, chemical and mechanical polishing and many process physical and electrochemical parametric measurement equipment. When the IRONMAN methodology is followed, there have been many success stories. The following is typical IRONMAN reliability data from equipment for semiconductor manufacturing. This success story has been repeated many times with equipment suppliers running IRONMAN. The equipment manufacturer's names have been purposely left out for anonymity.

The goals that were established for this IRONMAN program were as follows:

- Measure the reliability performance of the equipment. Reliability goals were included in the SOW.
- Establish a system for problem identification and resolution.
- Implement solutions to identified reliability problems and measure improvements.
- Perform regular process and system performance measurements for statistical process control.

The plan was to divide the IRONMAN into three periods for the purpose of setting program milestones. Each IRONMAN period followed the same procedure as follows:

- Cycle daily on second and third shift

- Use a two-step process and run wafers six times each
- Record reliability information per E10–92 SEMI standard for Reliability, Availability, and Maintainability definitions

The resources that had to be provided by the supplier included:

- Operators and technicians needed for the off-shift operation
- Hardware and software support from a design engineer and software engineer
- Manufacturing engineer to address process concerns
- Test engineer to plan and conduct tests to achieve test coverage, verify functionality, assign and maintain operators
- Quality assurance to ensure that the defined processes are followed, and corrective action is taken, to maintain configuration control and identify problems for sub-supplier
- Reliability engineer to do root cause analysis and provide the necessary reliability skills for analyzing data; FRACAS; developing metrics; determining test type, test length, and test evaluation; and training the technicians
- Reliability manager to drive the FRB, maintain check points, assign responsibilities, and own the IRONMAN methodology
- Project manager to plan the project, obtain the resources, ensure safety, maintain checklist of what needs to be accomplished

During the first IRONMAN period, the IRONMAN methodology was established, initial reliability problems with the tool were identified, and a methodology for diagnosing, resolving, validating, and implementing solutions to reliability problems using FRACAS was performed.

During the second period of IRONMAN, there was testing of hardware and software improvements that were identified and resolved from the first IRONMAN period. The testing schedule was modified to enable unattended cycling over the weekend to increase the throughput and consequently improve the cycle of learning.

During the third period of IRONMAN, process-related statistical process control measurements were initiated, major modifications for improving the equipment were tested, and partial capacity of the equipment was reserved for process development activity.

The IRONMAN results are summarized in Table 7. Throughput was charted over all three periods and shown to increase dramatically.

*Table 7. IRONMAN Summary*

| | **IRONMAN I (04/25 to 7/1)** | **IRONMAN II (7/6 to 7/12)** | **IRONMAN III (9/24 TO –––)** |
|---|---|---|---|
| Wafers Cycled | 14559 | 9753 | 2104 |
| System Productive Time (hours) | 437 | 245 | 96.94 |
| Total # of Equipment Related Incidents | 150 | 16 | 2 |
| Total # of Non-Equipment Related Incidents | 20 | 1 | 0 |
| Mean Wafers Between Interrupts (MWBI) | 97 | 610 | 1052 |
| MWBF (wafers) | 310 | 1219 | 1052 |
| Throughput (1 module) (wafers/hour) | 18 | 21 | 22 |
| Operational Utilization | 23% | 33% | 50% |
| MTTR (hours) | 0.616 | 0.640 | 0.440 |

Between IRONMAN I and IRONMAN II, an FRB (Failure Review Board) was established to review statistical failure data and to drive the recommended corrective action changes. Note that non-related equipment incidents and operator-induced failures decreased with time as the IRONMAN operations team gained experience in running the equipment tests. Pareto analysis from the IRONMAN program and field data was used to drive changes. Regular meetings and corrective action programs were initiated with the original equipment manufacturers, and a software action plan was developed.

Software failures accounted for 86 of 170 incidents in IRONMAN I and 9 of the 17 incidents in IRONMAN II. The Reliability Growth rate was high enough for completion of IRONMAN testing on time, and to provide equipment that was ready for the demonstration of its reliability in a Marathon test.

# NOTES

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