APPLIED Co$t MODELING

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Inside

Hi-Tech Equipment Reliability A Practical Guide for Engineers and the Engineering Manager

By Dr. Vallabh H. Dhudshia
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High-Tech Equipment Reliability Series

WWK recently received permission to reprint sections from Dr. Vallabh H. Dhudshia's book, *Hi-Tech Equipment Reliability: A Practical Guide for Engineers and Managers*. This book, first published in 1995, is now *back in print:*

http://www.iuniverse.com/bookstore/book_detail.asp?isbn=978-0-595-69727-4

Dr. Dhudshia has been an equipment reliability specialist with Texas Instruments and with Xerox Corporation. He served as a Texas Instruments assignee at SEMATECH for three years. Dr. Dhudshia received a Ph.D. in IE/OR from New York University. He is an ASQ fellow and a senior member of ASME. He has developed and taught courses in equipment reliability overview and design practices. He is an affiliate of WWK, specializing in reliability consulting.

In this issue of Applied Cost Modeling we are reprinting Chapter 11. We hope that you find the information in this series useful.

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Calendar of Events

March 2010

16-18 SEMI/SOLAR/FPD-CON
New International Exhibition Centre
Shanghai, PRC

May 2010

18-19 Utility Solar Conference
Denver Marriott City Center
Denver, Colorado

19-21 SEMICON Singapore
Suntec
Singapore

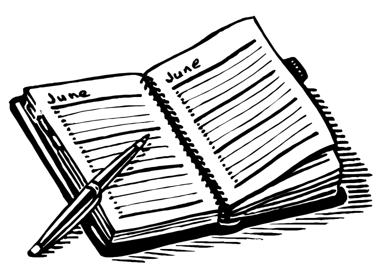
June 2010

9-11 Intersolar Europe
New Trade Fair Centre
Munich, Germany

July 2010

13-15 SEMICON West/Intersolar North America
Moscone Center
San Francisco, California

15 Understanding & Using Cost of Ownership
San Francisco Marriott
San Francisco, California



Chapter 11
Reliability Testing

No matter how many or how extensive the analyses we perform to calculate the reliability level of equipment[2], it is almost impossible to calculate the effect of all the factors that affect reliability level. Even after engaging complex reliability modeling software programs to do the reliability level calculations, we cannot theoretically include the effect of those factors to derive the exact reliability level that will be observed in a reliability test or when equipment is installed at the customer's site. This lack of certainty in our theoretical efforts necessitates performing reliability tests to find the actual reliability level of the tested equipment configuration.

Reliability testing is a very important activity of any reliability improvement program. The tests provide the proof for all the theoretical calculations and promised performance indices. Information generated during the reliability test is vital to design engineers for initial designs and subsequent redesigns or refinements, as well as to manufacturing engineers for fine-tuning the manufacturing process. The reliability tests also provide vital information to program managers showing technical progress and problems of an equipment line.

Reliability tests can be performed at any level of integration, i.e., at the component level, part level, module level, subsystem level, or system level. Not only that, they can be performed during any equipment program life cycle phase.

Among the numerous reasons to conduct reliability tests are:

[2] Note: The text of this chapter refers to equipment only. However, the reliability tests described in this chapter apply to parts, subsystems, and modules equally well.

- To determine the reliability level under the expected use conditions
- To qualify that the equipment line meets or exceeds the required reliability level
- To ensure that the desired level is maintained throughout the equipment life cycle phases.
- To improve reliability by identifying and removing root failure causes

11.1 Types of Reliability Tests

Since reliability testing is included in all the equipment life cycle phases and they are conducted for numerous reasons, it follows that the testing includes many types of tests. The following reliability tests are commonly seen during a typical equipment program.

1. Burn-in test
2. Environmental Stress Screening (ESS) test
3. Reliability development/growth test
4. Reliability qualification test
5. Product Reliability Acceptance Test (PRAT)
6. Accelerated test

Now let us understand each type in a little more detail.

Burn-in Test

This test is conducted to screen out parts that fail during the early life period (see figure 2.7, ACM Spring 2007). It is performed at part, subsystem, or system level. Most failures observed during this test are due to manufacturing workmanship errors, poor quality parts, and shipping damage. The system level burn-in tests are also known as debug tests.

Environmental Stress Screening Test

As the title indicates, the ESS tests are conducted in an operating environment that is harsher (a higher stress level) than the normal environment for expected use. The main purpose of the test is to weed out marginally defective parts that otherwise would not fail under normal operating environment screening. This test increases confidence that all received parts are of good quality and they will last longer (i.e., have better reliability).

Reliability Development/Growth Test
The reliability development/growth tests are conducted to ensure that a desired reliability level is achieved during a given equipment program life cycle phase and it is improving (growing) as the program moves further in the life cycle phases. Most of these tests are conducted at the system level.

Reliability Qualification Test
This test is conducted to qualify that the part or equipment meets or exceeds the reliability level. This is a pass/fail test. If the demonstrated reliability level is equal or better than the required level, the equipment (or its program) is considered to have met the requirement, thereby passing the test or qualifying the situation.

Product Reliability Acceptance Test
This test is very similar to the Reliability Qualification Test, except it is conducted on equipment randomly selected from among those that are ready to ship to customers.

Accelerated Test
Reliability development or qualification tests are normally too long to provide the needed information quickly enough to make decisions or to permit changes. To circumvent this, many equipment manufacturers employ a testing technique called accelerated testing. In this technique, operational stresses are increased so that the expected failure will arrive in a shorter time than it takes under normal operational stresses. This way, we compress the calendar time, that is, we accelerate the tests. Once the equipment life (reliability level) is determined under the higher operational stresses, the observed life is inferred for a normal operating environment. The most commonly used acceleration techniques are listed below.

- Enlarge the sample size (e.g., test eight units instead of three)
- Increase usage rate (e.g., run test at one hundred cycles per hour instead of normal rate of forty)
- Increase operational stresses (e.g., run test with one hundred–pound load instead of forty pounds)
- Increase environmental stresses (e.g., run at 120ºC. instead of at 30ºC)
- Combine any of the above techniques

11.2 Generic Steps for Reliability Tests

Three generic steps of any typical reliability test are:

1. Test plan development
2. Test conducting
3. Test data analysis and reporting

Test Plan Development
Test plan development is a very essential and crucial step for any reliability test. A well thought-out test plan ensures a flawless test and collection of dependable data. Such test includes the following items, at minimum:

- Test objectives
- Hardware and software to be used
- Operational stresses and environment
- Resources required (including consumable)
- Sample size and test length

- Test procedure
- Data to be acquired
- Data form to be used
- Data analysis techniques
- Data reporting and reviewing procedures
- Pass/fail criteria, if required
- Expected outcome for each test
- Types of test reports
- Schedule of key test activities

The reliability test plan should be formally documented and approved and funded by high-level management.

Test Conducting

If the reliability test plan is prepared as described above, the test conduction is very simple. During this step, the reliability test is conducted according to the test plan. All deviations from the formal test plan should be recorded and approved. A formal log of test events is kept to record the key test parameters associated with each event.

Test Data Analysis and Reporting

All the data collected during the test are appropriately analyzed, and conclusions are made. Test data, results, and conclusions should be reviewed by the FRB and other interested groups. To close a test project, a formal test report must be issued containing test objectives, test procedures, findings, conclusions, and recommendations.

11.3 Reliability Tests throughout the Equipment Program Life Cycle Phases

As shown in chapter 8 (ACM Winter/Spring 2009), reliability tests are scattered throughout the equipment program life-cycle phases. They play a very important part in the Reliability Improvement Process (RIP). Table 11.1 lists the appropriate tests for each phase.

11.4 Test Length

The test length depends upon the desired confidence in the test results and the expected level of reliability (MTBF). Tests need to run long enough to increase confidence in the test results. However, we usually do not have enough resources or time to test for an extended period. Therefore, statisticians have developed a method to determine the minimum test length needed to make correct decisions with the required confidence in those decisions. There are many test length tables available to fit any test circumstances. See references 1 and 2 for such tables. For repairable equipment, minimum test lengths are determined to obtain the certain minimum MTBF level (target MTBF) with certain confidence, by (equation 11.1):

$$\textit{Minimum test length with P\% confidence} = (\textit{Target MTBF})x\omega$$

WHERE:

P% = Desired confidence level
Target MTBF = MTBF to be proved or expected
ω = Appropriate multiplier for P% from table 11.2

For example, if we need to prove target MTBF of 100 hours, with 80% confidence in the decision, the minimum test length is calculated as follows.

Target MTBF = 100 hours
ω = 1.61 from table 11.2 for 80% Confidence Level

These give a minimum test length = 100 x 1.61 = 161 hours.

Life Cycle Phase	Reliability Test
Concept and Feasibility	No Formal Reliability Test
Design	Part-Level Reliability Qualification Reliability Development Accelerated Test
Prototype	Part-Level Reliability Qualification Reliability Qualification Reliability Growth Accelerated Test
Pilot Production	Burn-in Environmental Stress Screening System-Level Reliability Qualification Accelerated Test Reliability Growth
Production	Burn-in Environmental Stress Screening Reliability Qualification Product Reliability Acceptance Test Accelerated Test Reliability Growth
Phase Out	None Recommended

Table 11.1 Reliability Tests throughout the Equipment Life Cycle Phases

	Confidence Level P						
	10%	20%	50%	75%	80%	90%	95%
Multiplier ω	0.11	0.22	0.69	1.38	1.61	2.3	2.99

Table 11.2 Minimum Test Length Multiplier ω

11.5 Test Data Analysis

Reliability textbooks contain many formulas determining the observed reliability level and the associated confidence limits. For our repairable equipment, the following simplified method can determine lower confidence limits for the observed MTBF with the desired confidence level (equation 11.2).

$$P\%\ \text{lower confidence limit for the observed MTBF} = (\text{observed MTBF})xK$$

WHERE:

P% = Desired confidence level
Observed MTBF = MTBF calculated based on the test length and number of failures observed
K = Appropriate multiplier, from either table 11.3 or table 11.4, for the number of failures observed during the test and the desired confidence level

Use Table 11.3 for failure truncated tests (tests are terminated after the nth failures). For time/cycle truncated or fixed length tests, use table 11.4.

EXAMPLE:

If a reliability test was terminated after third failure and 10,000 hours, then

Observed MTBF = 10,000/3 = 3,333 hours
K factor for 3 failures and 80% confidence level is 0.701 from table 11.3,

Therefore, using equation 11.2

80% Lower confidence limit = 3,333 x 0.701 = 2,336 hours

REFERENCES

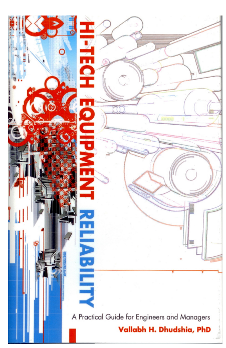
1. 1. W. Grant Ireson, Reliability Handbook (New York, NY: McGraw-Hill, 1966).
2. 2. Robert E. Odeh and Martin Fox, Sample Size Choice (New York, NY: Marcel Dekker, 1975).

Number of Failures	Confidence P					
	70%	80%	85%	90%	95%	97.50%
1	0.831	0.621	0.527	0.434	0.334	0.271
2	0.820	0.668	0.593	0.514	0.422	0.359
3	0.830	0.701	0.635	0.564	0.477	0.415
4	0.840	0.725	0.662	0.599	0.516	0.456
5	0.849	0.744	0.688	0.626	0.546	0.488
10	0.878	0.799	0.755	0.704	0.637	0.585
15	0.895	0.828	0.790	0.745	0.685	0.639
20	0.906	0.846	0.810	0.772	0.717	0.674
30	0.920	0.870	0.841	0.806	0.759	0.720

Table 11.3 Multiplier K for the Lower Confidence Limit Calculations for Failure Truncated Tests

Number of Failures	Confidence P					
	70%	80%	85%	90%	95%	97.50%
0	0.831	0.621	0.527	0.434	0.334	0.271
1	0.410	0.334	0.297	0.257	0.211	0.179
2	0.553	0.467	0.423	0.376	0.318	0.277
3	0.631	0.544	0.499	0.449	0.387	0.342
4	0.679	0.595	0.550	0.500	0.437	0.391
5	0.714	0.632	0.589	0.539	0.476	0.429
10	0.802	0.733	0.694	0.649	0.590	0.544
15	0.841	0.781	0.745	0.704	0.649	0.606
20	0.864	0.809	0.777	0.739	0.688	0.647
30	0.892	0.844	0.816	0.783	0.737	0.700

Table 11.4 Multiplier K for the Lower Confidence Limit Calculations for Time/Cycle Truncated or Fixed Length Tests



Wright Williams & Kelly, Inc. Conducts 4th Annual Semiconductor Manufacturing Technology Survey

Will Economic Upturn Change the View of 450mm Wafers?

Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today the start of its 2010 survey on equipment and process timing in the semiconductor industry. The survey results will be consolidated and provided to all participants free of charge. Participation in the survey is the only way to receive a full set of results. The survey form can be downloaded from the WWK web site at: http://www.wwk.com/2010survey.pdf.

Last year's survey showed that respondents expect to see the following manufacturing technologies in production by 2010:

- Double patterning
- Equipment suppliers using remote diagnostic capability
- Manufacturing capacity, utilization and cycle time simulation
- Implementation of 300mm prime advances

However, survey respondents did not expect to see the following technologies in production until 2013 or beyond:

- 193 high index immersion lithography
- Direct write
- EUV lithography
- Imprint lithography

With more than 3,000 users worldwide, Wright Williams & Kelly, Inc. is the largest privately held operational cost management software and consulting company serving technology-dependent and technology-driven organizations. WWK maintains long-term relationships with prominent industry resources including SEMATECH, SELETE, Semiconductor Equipment and Materials International (SEMI), and national labs and universities. Its client base includes nearly all of the top 20 semiconductor manufacturers and equipment and materials suppliers as well as leaders in nanotechnology, micro-electro-mechanical systems (MEMS), thin film record heads, magnetic media, flat panel displays (FPD), solid state lighting/light emitting diode (SSL/LED), and photovoltaics (PV).

Winter Simulation Conference
Integration & Collaboration

WSC 10

Marriott Waterfront Hotel
Baltimore, Maryland
December 5-8, 2010

Call for Papers

6th International Conference on
Modeling and Analysis of Semiconductor Manufacturing (MASM) 2010

Baltimore, Maryland, USA
December 5-8, 2010

The 2010 International Conference on Modeling and Analysis of Semiconductor Manufacturing (MASM) will again be a forum for the exchange of ideas and best practices between researchers and practitioners from around the world involved in modeling and analysis of high-tech manufacturing systems. We are convinced of the worth and importance of the continuation of the MASM events held in Tempe, Arizona in 2000 and 2002; Singapore in 2005; Miami, Florida in 2008; and Austin, Texas in 2009.

The MASM 2010 conference will be fully contained within the Winter Simulation Conference 2010 (WSC 2010), the leading conference in discrete event simulation (http://www.wintersim.org). WSC 2010 features a comprehensive program ranging from introductory tutorials to state-of-the-art research and practice. WSC 2010 will take place in Baltimore, Maryland, USA. All attendees of the MASM conference will register for WSC 2010 at the same cost. All participants of WSC 2010 can attend MASM 2010 sessions.

While historically we sought to examine the current integrated circuit (IC) semiconductor industry state-of-the-art, neither presenters nor attendees need to be in the IC industry to participate. We are interested in any methodologies, research, and/or applications from other industries such as thin film transistor-liquid crystal display (TFT-LCD), flexible displays, bio-chip, solid state lighting/light emitting diode (SSL/LED), and photovoltaics (PV) that might also share or want to share common and new practices.

In the face of the challenges driven by the likes of Moore's Law and "grid parity," continuous cost reduction, technology evolution, novel theoretical developments, and empirical studies are needed to maintain profitable growth of high-tech industries. In particular, to deal with increasing complexity in processes and materials as well as shorter life cycles and faster ramps, improvements at all levels are expected to contribute to future cost reductions and industry growth. At the operational level, improvements to equipment and operator productivity are as important as ever. At the system level, capital effectiveness and operational improvements are expected to make very significant strides. And at the strategic level, factory economics and supply chain efficiency promises to magnify equipment and factory level advances upstream and downstream in the business. To achieve this, economical analysis, new statistical methods, and enabling computing techniques will be required in addition to operations research methods. We invite you to present on topics related to modeling and analysis that will help address these challenges.

The conference includes tutorials and related software demonstrations within WSC 2010. A broad range of papers is sought, including theoretical developments, applied research, and case studies. Interested individuals within academia, government agencies, equipment and material suppliers, device manufacturers, students, contractors, and other interested parties are encouraged to participate.

The conference will be built around the following three tracks:

1. Operational Modeling and Simulation
2. Manufacturing Economics
3. Photovoltaics (PV) and Solid State Lighting/Light Emitting Diode (SSL/LED)

Conference Location

WSC 2010 will be held in vibrant Baltimore, Maryland at the Marriott Waterfront Hotel, December 5 – 8, 2010. The Marriott is located in the rejuvenated Inner Harbor area of this exciting city, a short stroll away from Baltimore's world-famous aquarium and many other attractions such as tall ships and submarines, Orioles Park at Camden Yards, and the Maryland Zoo as well as the primary district for entertainment, shopping and dining. The hotel is easily accessible from all three airports in the region, namely BWI, Reagan National, and Dulles International. The Baltimore Marriott Waterfront features 490 luxurious rooms with views of the harbor and downtown Baltimore. Hotel amenities include high speed internet access, two restaurants, a bar and a coffee shop, and a full service health club and spa with a modern fitness center and pool.

Conference Organizers

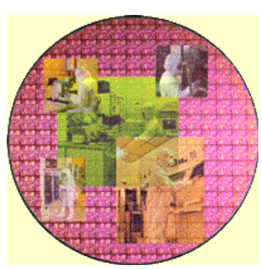
Enver Yucesan, INSEAD, Enver.YUCESAN@insead.edu (Program Chair, WSC 2010)
David Jimenez, Wright Williams & Kelly, Inc., david.jimenez@wwk.com

Paper Submission

Please follow the WSC 2010 Author Kit to prepare your MASM 2010 paper at http://www.wintersim.org.

Important Dates

Deadline for Paper Submission April 1, 2010
Notification of Acceptance June 7, 2010
Camera Ready Paper due July 16, 2010



COO Papers in Photovoltaics International

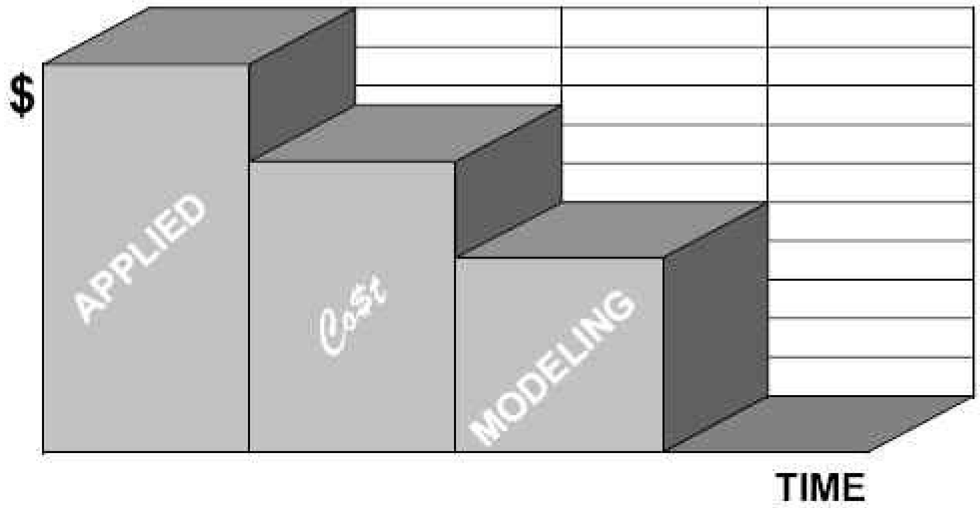
Photovoltaics International's 6th edition contains a paper written by Wright Williams & Kelly, Inc. The journal can be obtained at http://www.pv-tech.org. The abstract is: It is not surprising that the photovoltaics (PV) industry has adopted many of the same metrics developed for the semiconductor industry. With suppliers serving both markets, Semiconductor Equipment and Materials International (SEMI) organized the PV Group to, among other things, look at the portability of standards between these two industries. This paper will examine the application of two such standards, Guide to Calculate Cost of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment (SEMI E35) and Standard for Definition and Measurement of Equipment Productivity (SEMI E79). This latter standard also includes Overall Equipment Efficiency (OEE). Recent work at the National Renewable Energy Laboratory (NREL) regarding cost reduction also references SEMI E35. The application of these standards is examined using a case study comparing an in-line doping furnace and a $POCl_3$ batch furnace.

This is the first paper in a series that was commissioned by Photovoltaics International on the topic of COO and operational modeling. The second paper will appear in the 7th edition to be published in the March 2010 time frame. This paper, the second in a series covering COO studies for photovoltaics, examines the need for saw damage removal and the follow-on processes of pre-cleaning, texturization and cleaning. It further discusses the process considerations for wet and plasma approaches before taking a detailed look at texturization using random pyramid formation. The paper will conclude with a view of current and future wet process techniques and a COO case study using the Akrion Systems GAMA-Solar as an example.

The third paper in this series is set to examine front and back-side metallization of silicon solar cells.

WWK Starts User Group on LinkedIn

Wright Williams & Kelly, Inc. has established the "WWK User Group" on LinkedIn (http://www.linkedin.com/groups?gid=2829158&trk=anetsrch_name&goback=%2Egdr_1268167336471_1). This user group is designed to allow WWK software and consulting clients an opportunity to connect and share experiences with like-minded individuals. WWK has also established subgroups for more specific product support in the areas of TWO COOL, PRO COOL, Factory Commander, and Factory Explorer.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