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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 10. We hope that you find the information in this series useful.

[Continued on Page 3]

Editorial Board

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Calendar of Events

December 2009

17-19 International Conference on the Developments in Renewable Energy
United International University
Dhaka, Bangladesh

January 2010

10-13 Industry Strategy Symposium (ISS)
The Ritz-Carlton
Half Moon Bay, CA

February 2010

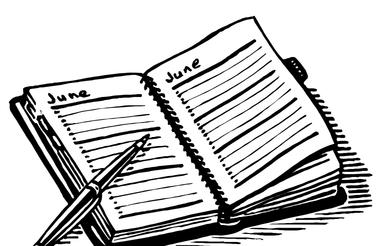
2-4 Photovoltaic Technology Show
Moscone Center, West Hall
San Francisco, CA

3-5 SEMI/SOLAR/LED-CON
COEX
Seoul, South Korea

March 2010

7-9 PV Fab Managers Forum
Hotel Park Inn
Berlin Alexanderplatz, Germany

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



Chapter 10
Three Reliability Growth Mechanisms

The reliability level of equipment improves in three ways: (1) with age during the early life of equipment after installation, (2) with the maturity of an equipment program throughout the equipment program life cycle phases, and (3) from one equipment generation to the next generation. This means that aged equipment has better reliability than new equipment, and equipment manufactured later in the equipment program production phase is more reliable than that manufactured earlier. Also, the recent generation of equipment is more reliable than the earlier generations. This phenomenon of reliability growth over time has long been recognized and has been studied by many experts. They have developed many empirical formulas to model the growth mathematically (see references 1 and 2). This chapter describes three growth mechanisms and presents a widely used mathematical model for each mechanism. The growth mechanisms include:

1. Reliability growth mechanism during the early life of equipment
2. Reliability growth mechanism throughout the program life cycle phases of the equipment program
3. Reliability growth mechanism from one generation to next generation

See chapter 7 to understand the difference between equipment and an equipment program.

Let us examine the three growth mechanisms in detail.

10.1 Reliability Growth Mechanism during the Early Life of Equipment

As shown in figure 2.7, reliability improves (i.e., failure rate decreases) as equipment gets older and then stabilizes at a constant rate. This growth period, as described in chapter 7, is known as the infant mortality period. Reliability growth during this period occurs by finding and removing manufacturing and workmanship defects.

Reference 3 has shown that the time to failure (in this period) follows a well-known Weibull distribution with a shape parameter β, of less than 1. The failure rate is given by equation 10.1:

$$\lambda(t) = \frac{\beta}{\eta} x \left(\frac{t}{\eta} \right)^{(\beta - 1)}$$

WHERE:
$\lambda(t)$ = Failure rate at age t during the early life period.
β = Shape parameter, $0 < \beta < 1$, also known as reliability growth rate constant.
η = Scale parameter, $\eta > 1$, also known as 36.8 percentile point.

Use the above model to determine realized reliability growth for a unit of equipment and to predict $\lambda(t)$ at time t for the similar equipment. To determine the realized growth, collect failure rate λ (t) at a given age t data for a sample of units of equipment and fit them to equation 10.1 to determine the least square fit values of growth parameters β and η. See reference 2 for more details. For example,

t	$\lambda(t)$
50	$1.740x10^{-3}$
100	$1.318x10^{-3}$
200	$1.000x10^{-3}$
400	$0.757x10^{-3}$
1000	$0.528x10^{-3}$

The least square fit value for $\beta = 0.6$ and $\eta = 1{,}250$.

Once the growth parameters are known, use equation 10.1 to calculate predicted values of $\lambda(t)$ at any time t for the similar equipment (i.e., having similar configuration) during the early life period.

For example, if $\beta = 0.6$ and $\eta = 1{,}250$ then $\lambda(600) = 0.644x10^{-3}$ failures per hour

Note that growth parameters change with the equipment program maturity, as explained in the next section.

10.2 Reliability Growth Mechanism throughout the Equipment Program Life Cycle Phases

The second reliability growth mechanism originates from the continuous reliability improvement activities described in chapters 8 and 9. This growth mechanism shows that equipment manufactured later in the equipment (program) production phase is more reliable than that manufactured earlier. This growth is a result of finding and removing design defects, misapplied parts, manufacturing errors, software errors, and service procedure and training deficiencies. Figure 10.1 shows the difference between the first two reliability growth mechanisms.

As shown in references 1 and 2, this growth mechanism is extensively studied, and experts have developed several mathematical models to describe it. One of the models, more appropriate for an equipment program, is known as *Duane MTBF Growth Model*. This model is given as equation 10.2:

$$MTBF(T_a) = MTBF(1)x(T_a)^{\alpha}$$

WHERE:

T_a = Accumulated hours of test and/or field experience.

$MTBF(T_a)$ = Cumulative MTBF after T_a accumulated hours of test and/or field experience.

$MTBF(1)$ = MTBF at T_a =1 or at the beginning of the test, or the earliest time at which the first MTBF can be determined

α = Reliability growth rate constant, $0 < \alpha < 1$.

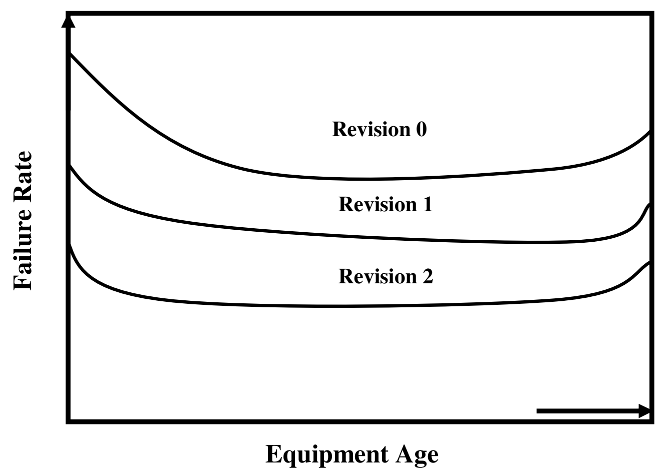


Figure 10.1 Reliability Growth Mechanisms

A closer look at equation 10.2 reveals that value of α drives the MTBF growth. Therefore, proper selection of value of α is very important. The value depends upon equipment type, quality of parts, and aggressiveness of the reliability improvement efforts. One way to determine α is to collect cumulative MTBF and corresponding T_a data and fit them to model equation 10.2 to determine the least square fit value of *MTBF*(1) and α. For example,

MTBF(200) = 100 hr
MTBF(400) = 133 hr
MTBF(600) = 150 hr, and
MTBF(3,000) = 273 hr

gives the least square fit value of *MTBF*(1) = 14 and α = 0.376.

In the absence of such data, use table 10.1 as a guideline to select appropriate value of α.

Use the least square fit or tabulated values in equation 10.2 to calculate predicted value of $MTBF(T_a)$ for the equipment manufactured after T_a hours of accumulated test and/or field experience.

Types of Reliability Improvement Program	**α**
No formal reliability improvement program	0.20
Reactive informal reliability improvement program	0.45
Proactive formal reliability improvement program with failure reporting and corrective action system in place	0.65

Table 10.1 Recommended Values of Reliability Growth Constant α

For example, if *MTBF*(1) is 14 hours, α = 0.376, and T_a = 5000 hours, then the expected cumulative MTBF after 5000 hours of accumulated test is 344 hours.

The reliability growth curve is a powerful tool for managing Continuous Improvement Process (CIP) and predicting reliability level for the future configurations.

10.3 Reliability Growth Mechanism from One Generation to Next Generation

Our experience shows that every time we create a new generation of equipment, the new generation is more reliable than the older one. This reliability growth mechanism originates from continuous reliability improvement activities, learning and transferring reliability improvement knowledge to the next generation, and technological advances. So far, no systematic studies have been conducted to formulate this growth mechanism. As a result, there are no mathematical models that quantify this growth mechanism. In absence of such studies, we can use models given in equations 10.1 and 10.2, with higher values of growth parameters α and β, to predict reliability of equipment manufactured during an equipment program in the next generation of equipment.

REFERENCES

1. R. E. Schafer, R. B. Sallee, and J. D. Torrez, *Reliability Growth Study* (Fullerton, CA: Hughes Aircraft Company, 1983).
2. Dimitri Kececioglu, *Reliability Engineering Handbook,* Volume 2 (Englewood Cliffs, NJ: PTR Prentice Hall, 1991).
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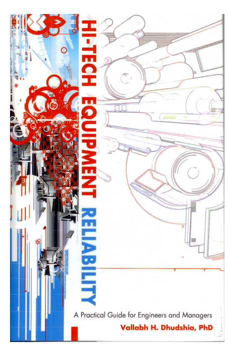


2009 Equipment Survey Results

Get Ready for the 2010 Survey

What a difference a year makes!

The annual Wright Williams & Kelly, Inc. (WWK) semiconductor equipment survey has uncovered some interesting changes since the 2008 survey was conducted. Some of these changes can be explained by the drastically different economic conditions, but some hint at fundamental changes in the way semiconductor business will be conducted in the future.

The 2008 survey was limited by insufficient responses in the following areas:

- Etch & Clean
- Deposition
- Gate Technologies

The 2009 survey had insufficient responses for analysis in the area of test and metrology. Thus, we cannot infer anything in these four areas, but will focus on lithography and manufacturing – areas with sufficient survey response for comparison.

Litho

In general, most potential next generation lithography technologies are now expected in production one to two years later than 2008 respondents reported. This is a clear indication that folks are taking economic factors into consideration in technology timing.

So if 193-nm high refractive index immersion, EUV, direct write, and imprint are expected to be pushed out, what is left for the next litho solution? The 2009 respondents report that double patterning is expected earlier than was expected in 2008. Thus, we expect that the various flavors of double patterning are being accepted even with the inherent issues of lower productivity. That isn't surprising since utilization rates are not the issue today, so excess capacity in litho can be absorbed by double patterning. The question is will this opinion change when the economy finally recovers.

Manufacturing

The big question is whether or not 450mm. In 2008, 56% responded that 450mm would “never happen.” In 2009, the percentage responding “never happen” had dropped to 17%, with production expected in 2015. This response is counter to what the survey shows with next generation lithography. We expected the two trends to be linked.

A related question is with regard to the implementation of 300mm Prime advances. The expected production year of 2009-2010 was about the same as reported in the surveys of both years, but in 2009 17% indicated that 300mm Prime advances will never be implemented. Again, it is our opinion that this is related to current economic conditions since 300mm Prime focuses on productivity improvements that may be perceived as not needed during a significant downturn.

The responses to these questions could result from several underlying expectations. Two possible explanations are:

- No further R&D or capital equipment investments will be directed toward 300mm but instead will be directed toward 450mm development, or,
- Equipment suppliers are pessimistic in both areas – no one has any money so why should they respond.

The good news is that in the 2009 survey, 83% of respondents indicated they expect the semiconductor industry to recover in 2010. Next year's survey will prove interesting.

Consumer Electronics
New to the 2009 survey were several questions about expected consumer electronics purchases as these are a driving force for the industry. Not surprising, the median year for the next laptop purchase is 2010 and the median year for the next netbook purchase is 2009. But the median year for the next desktop purchase is Never. Have desktops gone out of style to be replaced by more powerful laptops or by simple netbooks? Based only on the 2009 survey, that appears to be the trend. This has profound impacts on the semiconductor industry. WWK is conducting follow-up in this area and will report our findings in a month or so. Next year's survey will prove interesting.

The 2009 results for the areas discussed are summarized in the following table.

Litho		**Median Year**	**% Never**
	193-nm High Refractive Index Immersion	Never	67%
	Direct Write	Never	75%
	Double Patterning (2 resist steps)	2009	
	Double Patterning (1 resist step)	2010	20%
	EUV	2015	29%
	Imprint	2014	25%
	Directed Self Assembly Nano-Resists	2016+	20%
Manufacturing			
	450mm wafers	2015	17%
	Equipment with Energy Saving "Sleep" States	2011	
	Equipment Suppliers using Remote Diagnostic Capability	2010	17%
	Manufacturing Capacity, Utilization and Cycle Time Simulation	2010	
	Implementation of 300mm Prime Advances	2010	17%
	Semiconductor Upturn	2010	
Consumer Electronics			
	Desktop PC	Never	60%
	Laptop PC	2010	
	Netbook PC	2009	17%
	Interior LED Lighting	2011	
	Solar Electrical System (on Grid)	2013+	33%

For those interested in participating in the 2010 survey and receiving the results as they are available, please check back with WWK in early February 2010.

WWK Named Track Coordinator for MASM 2010

Winter Simulation Conference
Baltimore Marriott Waterfront
December 5-8, 2010
www.wintersim.org

Wright Williams & Kelly, Inc. (WWK), the world's preeminent operational modeling and simulation software and consulting services company, announced today that it will be the track coordinator for the 6th International Conference on Modeling and Analysis of Semiconductor Manufacturing (MASM) 2010 at the Winter Simulation Conference.

The MASM 2010 conference will be fully contained within the Winter Simulation Conference 2010 (WSC '10), the leading conference in discrete event simulation (http://www.wintersim.org). WSC '10 will feature a comprehensive program ranging from introductory tutorials to state-of-the-art research and practice. WSC will take place in Baltimore, Maryland, USA. All attendees of the MASM conference will register for WSC at the same cost. All participants of the WSC can attend MASM 2010 sessions.

As track coordinator, WWK will be looking to fill the following positions:

- Session Chairs
- Peer Review Members

Additionally, WWK will be soliciting papers on methods and applications of simulation as applied to semiconductor manufacturing. Anyone interested in submitting a paper or serving in a Chair or Review capacity can contact WWK at info@wwk.com.

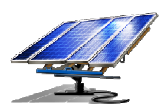
With more than 3,000 users worldwide, Wright Williams & Kelly, Inc. is the largest privately held operational cost management software and consulting company serving technology-dependent and technology-driven organizations. WWK maintains long-term relationships with prominent industry resources including 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), and photovoltaics (PV).

WWK's product line includes TWO COOL® for detailed process step level cost of ownership (COO) and overall equipment efficiency (OEE), PRO COOL® for process flow and test cell costing, Factory Commander® for full factory capacity analysis and activity based costing, and Factory Explorer® for cycle time reduction and WIP planning. Additionally, WWK offers a highly flexible product management software package that helps sales forces eliminate errors in product configuration and quotation processes.

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 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 cost of ownership and operational modeling. The second paper will appear in the 7th edition to be published in the February 2010 time frame. This paper will examine the current state of the art processing for saw damage removal, texturization, and cleaning for single crystal silicon photovoltaic cells. The paper will examine the need for these processes, the advantages they provide for cell efficiency, their COO, and projected areas for improvement in COO. This paper will be co-authored by industry expert Dr. Ismail Kashkoush, VP - Applications and Technology at Akrion Systems.



WWK Establishes Cooperative Agreements in Indian LED Market

Wright Williams & Kelly, Inc. (WWK), the global leader in cost and productivity management software and consulting services, announced the establishment of relationships with MK Krishnakumar, Integrated Cleanroom Technologies, and Light Efficient Designs/Xeralux. The purpose of these relationships is to promote a turnkey approach to business planning, equipment procurement, factory design and construction, and end market applications for high brightness LEDs in the Indian market. Stay tuned for additional information on these relationships and design wins.

WWK Takes Over Management of LinkedIn Group on COO

Wright Williams & Kelly, Inc. has taken over the management responsibility for the LinkedIn Group "*Total Cost of Ownership*." The charter of this group is to foster discussion of cost of ownership issues across industries. Anyone interested in joining the group can do so by doing a search by group at http://www.linkedin.com for "Total Cost of Ownership" and clicking on the "join this group" link.

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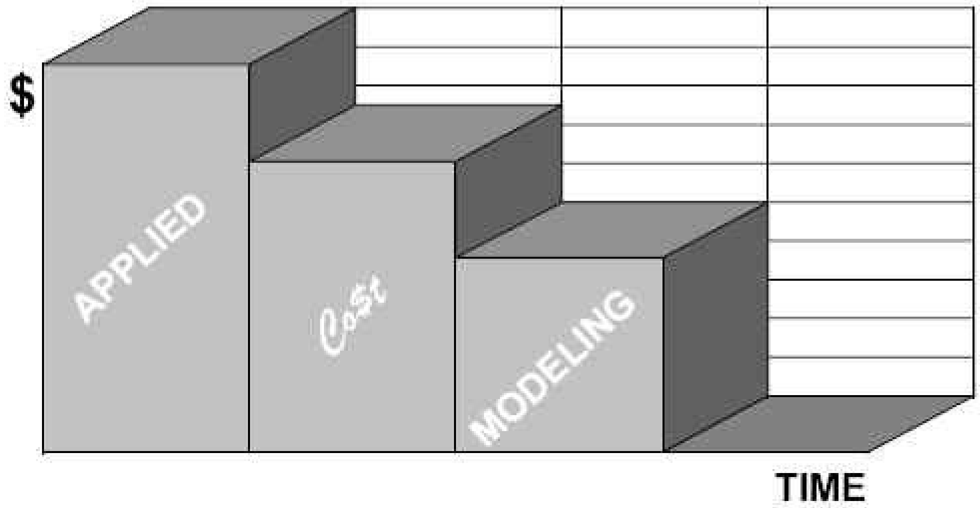
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