# APPLIED Co$t MODELING

Information Exchange For Your Application & Use of Cost Modeling

Volume 13. Issue 4


## Inside




Summary 2007

ISSN 1094-9739


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

By Dr. Vallabh H. Dhudshia

*Reprinted by Permission of the Author*[1]

### 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 the Engineering Manager*. This book, first published in 1995, is now out of print (second edition to be published later in 2007) but still provides useful guidance to the equipment engineering community as they strive to improve cost of ownership (COO).

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 the first half of Chapter 3. We hope that you find the information in this series useful.

[Continued on Page 3]

# Editorial Board



# Publisher

Published quarterly by:

Wright Williams & Kelly, Inc.
6200 Stoneridge Mall Road
3rd Floor
Pleasanton, CA 94588

Phone 925-399-6246
Fax 925-396-6174
E-mail support@wwk.com

Available at:
http://www.wwk.com
Select "Newsletter"

# Calendar of Events

## September 2007

**4-5** **SEAJ/SEMI Industry Strategy and Technology Forum (ISTF)**
**Yokohama, Japan**

## October 2007

**9-11** **SEMICON Europa**
**Stuttgart, Germany**

**23-25** **International Test Conference (ITC)**
**Santa Clara, CA**

## November 2007

**4-5** **International Trade Partners Conference**
**Maui, HI**

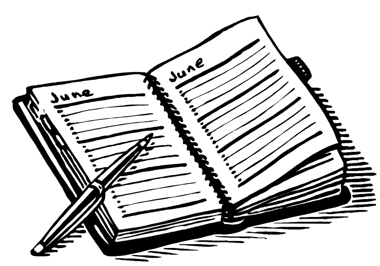
## December 2007

**3-7** **International Photovoltaic Science and Engineering Conference**
**Fukuoka International Congress Center**
**Fukuoka, Japan**

**5-7** **SEMICON Japan**
**Makuhari Messe, Japan**

## January 2008

**13-16** **Industry Strategy Symposium (ISS)**
**Half Moon Bay, California**



## Reliability Metrics

## 3.1 Introduction and Objectives

Experience shows that reliability metrics users often use a variety of terms that are not always precise and simple to understand. These terms may mean different things to different people, and the result is confusion, irritation, and animosity. This is particularly true for nonreliability engineering personnel. The most common confusion stems from a mix-up of reliability metrics and the application of those metrics. The purpose of this chapter is to define and categorize the most frequently used reliability metrics and their applications and then clarify their relationship with each other.

We will limit our discussion to exponential PDF, because failure times of almost all electronics components and those of most mechanical components follow exponential PDF. Also, distribution of the time between two successive failures of a repairable system is exponential (see chapter 4).

## 3.2 Two Main Categories of Reliability Terms

As mentioned above and shown in table 3.1, the terms used for the reliability metrics can be divided into two categories:

1. Reliability metrics
2. Applications of reliability metrics

The reliability metrics are various terms used to quantify the numerical value of the reliability levels, such as Mean Time Between Failures (MTBF), failure rate, and percent failed, etc.

Applications of reliability metrics are terms that are used with any reliability metrics. When the reliability metrics are used for a specific reliability related activity and/or a situation, it creates an application of the metric. The terms used for such application are applications of reliability metrics. Such terms (used for application of reliability metrics) enhance understanding of the associated reliability metrics. For example, any reliability goal-setting activity creates reliability goals. Goal is an application of the reliability metric, e.g., goal MTBF. It clarifies that the numerical value of the reliability metric represents a goal for the reliability level (and not an observed reliability level).

## 3.3 Categories of Reliability Metrics

Reliability metrics can be divided into four main categories:

1. Metrics based on probabilities
2. Metrics based on mean life
3. Metrics normalized by life units
4. Metrics expressed in percentage

**Metrics Based on Probabilities**

Probabilistic metrics are classical measures of reliability. They always contain a "probability statement." Three typical examples are given below:

1. Probability of performing intended functions for a specified time under stated operational conditions Pr[T > 1,000 hours] = 0.95
2. Probability of success of a mission Pr[S] = 0.95
3. Probability of survival for a specific time under stated conditions Pr[T > 1,000 hours] = 0 .95

**Metrics Based on Mean Life**

These metrics consist of at least four words, as shown in figure 3.1. Two of them, mean and between, are mandatory. Others relate to the measure of life and events.

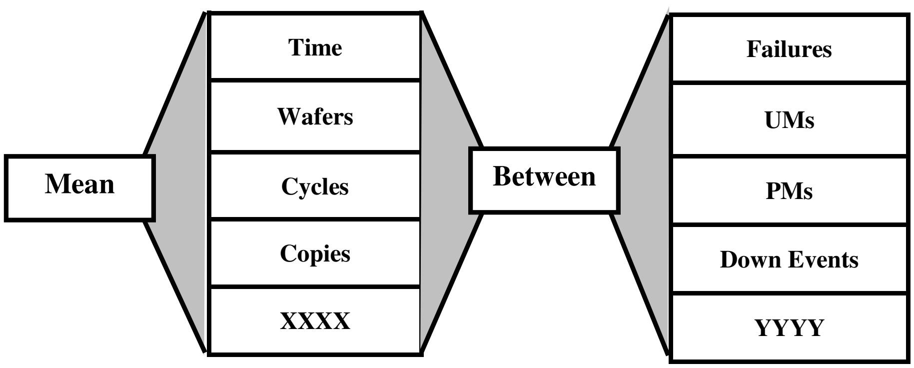
*Table 3.1 Two Main Categories of Reliability Terms*

| | |
|---|---|
| **Reliability Metrics** | MTBF |
| | MWBF |
| | MCBF |
| | Failures Per Million Hours |
| | Pr [ T > 1000 Hr] = 0.95 |
| | Pr [ S ] = 0.90 |
| | % Failed |
| | % Survived |
| | Down Events per 1000 Cycle |
| | UMs per Million Cycles |

| | |
|---|---|
| **Applications of Reliability Metrics** | Goals |
| | Requirements |
| | Design Specifications |
| | Allocations |
| | Apportionment |
| | Budgeted Goals |
| | Warranty |
| | Calculated Reliability |
| | Inherent Reliability |
| | Expected Reliability |
| | Predicted Values |
| | Observed Values |
| | Adjusted Observed Values |
| | Confidence Limits |

Using the algorithm given in figure 3.1, we can make many metrics: Use the word mean, select a word for measure of life, use the word between, and select the desired event.

*Figure 3.1 Reliability Metrics Based on Mean Life*




EXAMPLES:

- Mean Time Between Failures (MTBF)
- Mean cycles between down events
- Mean Wafers Between Failures (MWBF)

This is the most widely used category of the reliability metrics. Specifically, it is very widely used to track reliability of semiconductor manufacturing equipment and is recommended by the Semiconductor Equipment and Materials International (SEMI), an association of semiconductor manufacturing equipment suppliers, in SEMI specification SEMI E10-0304E for definition and measurement of equipment reliability, availability, and maintainability. See reference 1.

To calculate the numerical value of these reliability metrics, we need to know two basic elements of the reliability discipline: (a) number of life-units, or the measure of life used, the equipment was in operational condition during the period of interest, and (b) number of events that stop the equipment from performing its intended functions in the same period. Use the following equation to calculate the desired metric (equation 3.1).

$$\text{Reliability Metric} = \frac{\text{number of life units in the selected operational period}}{\text{number of events during the same operational life period}}$$

As shown in figure 3.1, events can be failures, down events, scheduled maintenance, or unscheduled maintenance. Operational life period can be expressed in calendar time, productive time, number of cycles, or number of wafers processed. Based on these variations, some popular reliability metrics for semiconductor manufacturing equipment are given by equations 3.2 and 3.3:

$$\text{Mean Productive Time Between Failures } (MTBF_p) = \frac{\text{productive time}}{\text{number of failures that occur during productive time}}$$

$$\text{Mean Cycles Between Failures}(MCBF) = \frac{\text{total equipment cycles}}{\text{number of failures}}$$

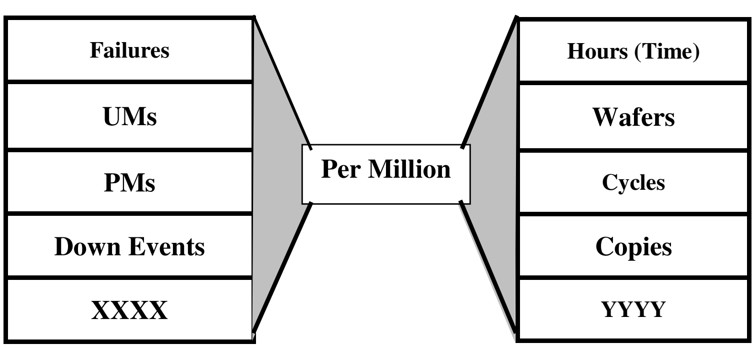
The above formula also applies to any measure of life by replacing "cycles" with the desired measures. For example (equation 3.4):

$$\text{Mean Wafers Between Failures}(MWBF) = \frac{\text{number of wafers processed}}{\text{number of failures}}$$

**Metrics Normalized by Life Units**

In this category, the numerical values are normalized by a desired number of life units.

*Figure 3.2 Reliability Metrics Normalized by Life Units*




Metrics in this category also have at least four words. Only one of them is mandatory; the others are selective, as shown in figure 3.2.

Using the algorithm given in figure 3.2, we can make many metrics of this category: select the desired event, use the word per, select the amount of normalization, and select the measure of life.

EXAMPLES:

- Failures per million hours
- UMs per thousand cycles

To calculate the numerical value of these reliability metrics also requires two basic elements of the reliability discipline: (a) number of life-units, of the measure of life used, the equipment was in operational condition during the period of interest, and (b) number of events that stop the equipment from performing its intended functions in the same period. Use the following equation to calculate the desired metric (equation 3.5):

$$\text{Reliability Metric} = \frac{\text{number of events in the selected operational period}}{\text{number of life units during the same operational period}}$$

These metrics can be expressed in events per thousand, million, etc., life units.

**Metrics Expressed in Percentages**

In this category, metric values are expressed in percentage.

EXAMPLES:

- 2% failed during first 1,000 hours
- 99% survived past 1 million cycles

ISSN 1094-9739

## 3.4 Applications of Reliability Metrics

The application of reliability metrics can be divided into the following three categories, depending upon the origin of the activities they represent:

1. Desired values
2. Analytical/theoretical values
3. Observed values

**Desired Values**

In this category, the value of the reliability levels originates from the reliability activities that deal with desires of equipment manufacturers and/or their customers.

EXAMPLES:

- The (reliability) goals are what a manufacturer wants his equipment to perform
- The (reliability) requirements are what a customer wants his equipment to perform.

Therefore, goals and requirements applications belong to the desired value category.

When the system-level goals or requirements are broken into department or subsystem level goals or requirements, based on some logical justification, they generate the applications known as allocation, budgeting, or apportionment, which also belong to the *desired values* category.

System-level reliability goals, allocated to subsystem and component, and corresponding operating environments, are parts of the respective design specifications for reliability. Therefore, design specifications are also an application of the reliability metrics and fall in this category.

Figure 3.3 depicts the hierarchy of and relationship among various desired values applications of the reliability metrics.

**Analytical/Theoretical Values**

In this category of applications, the value of reliability levels originates from appropriate theoretical reliability activities, such as modeling, part-count calculation, and stress analysis.

Following are three typical examples of the analytical/theoretical values category applications:

- *Inherent reliability*: The values are derived from design assessment, assuming benign environments and no error in design, manufacturing, and operation. The inherent reliability is the best achievable level.
- *Expected reliability*: When inherent reliability values are adjusted to account for design errors, manufacturing errors and quality problems, human errors, and operating environments, they become expected values.
- *Predicted reliability*: When the expected reliability and/or observed reliability values (defined in the next section) are adjusted to account for the planned corrective actions (design, manufacturing, and/or operational modifications), they become predicted values.

*Figure 3.3 Hierarchy of Applications of Reliability Metrics Belonging to Desired Values Category*

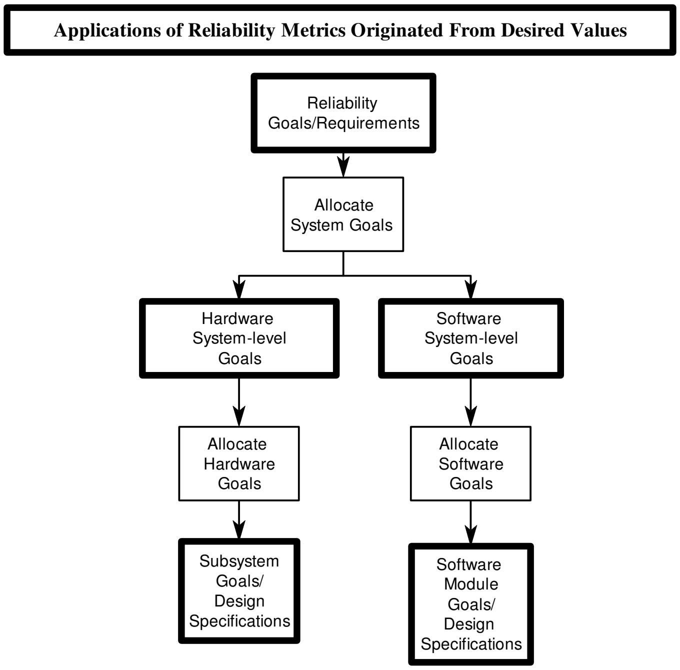



*Figure 3.4 Hierarchy of Applications of Reliability Metrics Belonging to Theoretical/Analytical Values Category*

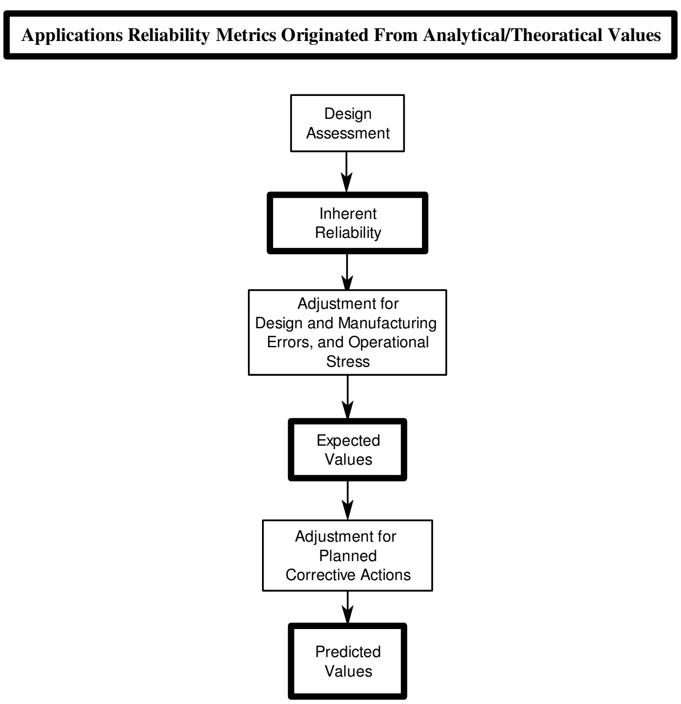



Figure 3.4 shows the hierarchy of and relationship among different applications of the reliability metrics originating from the analytical/theoretical values category.

**Observed Values**

This category represents situations in which the reliability level is established based on actual in-house test data, field test data, or field operations data of the equipment.

The following are three typical examples:

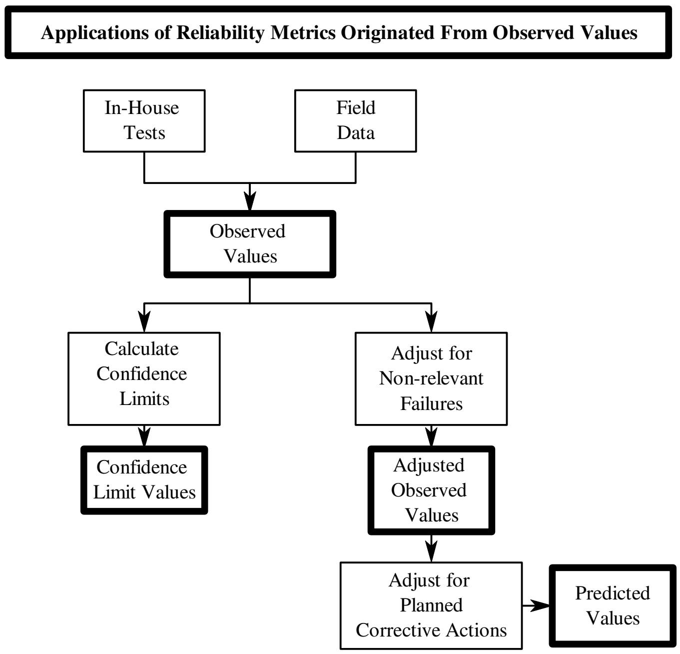
- Observed values: The values are derived from actual in-house tests, field tests, or field operations. These values are not altered or adjusted.
- Adjusted observed values: When observed values are adjusted to account for nonrelevant failures (such as facility problems or out-of-spec consumable) they become adjusted observed values.
- Confidence limit values: These values are the observed values adjusted to account for the number of failures observed, as described in section 3.6.

OTHER EXAMPLES:

- Observed MTBF of 500 hours during beta test.
- Observed MWBF of 8,000 wafers in the first quarter of 2007 with 90% confidence.

Figure 3.5 shows the hierarchy of and relationship among different applications of the reliability metrics originating from the observed values category.

*Figure 3.5 Hierarchy of Applications of Reliability Metrics Belonging to Observed Values Category*




## REFERENCES

1. SEMI Specification, SEMI E10-0304E, Guideline for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM) (San Jose, CA: SEMI International, 1986, 2004).

*WWK offers "Equipment Reliability Overview" training based on this book's content. This training can be customized for your organization. For more information, please contact WWK at info@wwk.com.*

[Look for installment 4 (the rest of chapter 3) in the fall edition of Applied Cost Modeling]

## Wright Williams & Kelly, Inc. Granted Software Patent

Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today that the U. S. Patent and Trademark Office has granted it a software patent titled "Method and Apparatus for Calculation of Production Quantities." The patent covers the company's novel research into equipment capacity analysis where there is hierarchal control of subsystems as in test cells and cluster tools. The company has embedded this intellectual property (IP) in its software product PRO COOL® for Wafer Sort & Final Test, a cost and capacity analysis tool for semiconductor test systems. PRO COOL® was recently used for a major evaluation of test system open architecture by the Semiconductor Test Consortium (STC).

"The software patent process has become extremely complex since the Internet bubble of the late 90s," stated David Jimenez, President of WWK. "Our IP attorneys have stated that the U.S. government wants to greatly reduce or stop the granting of software patents. The fact that we were granted this patent in such a well-established area speaks to the novelty and importance of our research and development. By embedding this IP in PRO COOL® for Wafer Sort & Final Test we are ready to address the critical concern of semiconductor cost of test (COT)."

"Testing semiconductor devices has not benefited from the same productivity gains that wafer manufacturing has enjoyed," stated Daren Dance, Vice President of Technology for WWK and lead inventor. "WWK has extensively studied test productivity. With this patent, we have demonstrated our commitment to help improve test productivity through our cost simulation and analysis tools."

## Spreadsheet Hell

You're invested in it. You've built a spreadsheet that answers so many questions. You have links that go up one worksheet and down the next. You've managed to use smart macros, specialized functions and clever workarounds; outputs layout nicely for the chart wizards so even the chart labeling has been automated properly.

You've managed all those small, yet critical, details; like discovering innovative ways to debug the linked spreadsheets. Making the entry boxes look nice and the calculation engines a work of art. You spent the time and energy and money. You can finally answer those important questions. And you should feel great, but you don't.

The moment has arrived where your boss has thrown in a wrinkle you hadn't anticipated; asked for one thing that your work wasn't designed to do. And what you notice most is that sinking feeling in the pit of your stomach. Like the juggler that keeps adding one more ball, your boss's incremental request sounds so much more innocent than it is. It's a feeling shared by thousands of people before you and will happen to thousands after you. This feeling has a name: *Spreadsheet Hell.*

It is the same feeling as having painted yourself into a corner, because that is what happened. You crossed a threshold. You find yourself needing to spend more time managing the spreadsheets than using them to get answers. Debugging has become a guessing game and new features tend to ripple in unexpected places. And yet momentum keeps you building even as you sense you are running into a wall. There is no easy way out.

Why is Spreadsheet Hell so Common?

Spreadsheets are incredibly powerful and flexible but are not designed to do everything. It's common to find 15 sheets, or more, that are linked together to do analyses. In areas like finance, capacity planning and scheduling, spreadsheets are ubiquitous.

The reality is that most spreadsheet-based projects are not done by spreadsheet experts. Instead they are experts in other areas, making use of spreadsheets as an effective tool to help answer their business questions. Spreadsheets, notably Excel, have easy learning curves and a wide array of features that allow a lot to be done. They are remarkable tools, but it is important to understand their limits as well as their benefits.

Building a spreadsheet into its own "hell" is often the path of least resistance. There is no budget allocated at the start. No purchase orders to push through. No time lag between seeing the need and getting started. There are no barriers. So the effort begins and starts to bear fruit. So you continue on.

Yet the complexity continues to evolve as the needs evolve. While the spreadsheet grows linearly, the coding complexity often grows exponentially and the debugging complexity is usually worse. Often times this process continues even after the user has lost confidence in their own ability to manage and debug the spreadsheet. In many cases, this loss of confidence is not shared with others, especially if the customer for the results of the spreadsheet is the boss.

ISSN 1094-9739

In a way, you are stuck dealing with a basic human instinct. Survival experts understand this. When lost in the wilderness, the instinctive tendency is to press on. Something is not right, but if you press forward, you will succeed. But the reality is that you are getting more lost. The right move, survival experts advise, is to retreat until you recognize where you are and re-orient yourself. Like being lost in the wilderness, spreadsheets can take you down the wrong path. You can start off in the right direction, but if you go too far, you will find yourself in spreadsheet hell.

Where Do Spreadsheets Hit the Wall?

The answer is surprisingly consistent. It happens when the ideal world meets the real world. In the areas of capacity and financial planning, people lay out spreadsheets with a 'greenfield' mentality, often using a single product and process.

The single most common question asked of WWK is, "Something is changing in my world and I want to understand what it means". Spreadsheets alone are notoriously unable to address that 'something' and rarely get to the 'what does it mean'.

For example, visibility is always better closer in than further out. But most spreadsheets look only at set time periods. In a long-term, financial model, you may want to see the near term on a monthly basis, the medium term on a quarterly basis and the long term on an annual basis. But spreadsheets like fixed time intervals, either years or quarters or months -- but not all three!

In high tech operations, very rarely do operations exist in a steady state for any length of time. There is always a ramp up of a new product and the ramp down of an older product. Equipment performance is a moving target. Spreadsheet models often struggle to add equipment when the user does. And they are even worse about removing existing equipment. Then just try to incorporate constantly changing process routes.

The variety of changes is virtually unlimited. As you scale up the materials use, the unit cost of the material changes. An upgrade can make the tool throughput faster this month as compared to last, but only on certain products. Yield improves as those involved with the operation gain experience, but a new product has its own learning curve. And that yield changes at both individual process steps and at the finish line. Rework loops, repairs, test process flows, metrology sampling, testing, automation, software, licensing, currencies, royalties, labs, QA, transformations, taxes, assemblies and other standard business functions are all stress points for most spreadsheets.

These situations are similar to that described in the opening. They are all redesign points, where the spreadsheet needs a substantial change as opposed to the simpler changes required during simpler times. Hindsight may show that a limited vision on the part of the customer of the spreadsheet analysis was a contributor to this redesign point. Or it may show that a deeper understanding of programming architecture could have been helpful. And the user may come to realize how many hats they are wearing. But none of this changes the basic situation. Yes, reality has its unpleasant ways of intruding on the best of spreadsheets.

What is the key to avoiding spreadsheet hell?

It is really a matter of keeping an eye on what is important. Spreadsheets are not an end, they are a means to an end. If the developer understands the value is not in the spreadsheet but in the questions that it answers, they have taken the most important step. Always look at the value of the answer and approach the problem from that perspective.

For example, if the answers needed are 'back of the envelope' quality, a spreadsheet can provide a useful answer. If the questions relate to real world complex environments, with lots of moving parts, then the spreadsheet will almost certainly be inadequate.

Sometimes the value is not directly tied to the answer or even the quality of the spreadsheet. For example, a supplier developed homegrown cost of ownership model is almost always a spreadsheet. And almost every customer will view it with intense skepticism. They will discount not just your numbers but also the underlying formulae. A spreadsheet that can be unlocked will never be as credible as secure third party models that conform to relevant standards.

A third caution is to be careful with assumptions and short-cut calculations. For example, many companies operate on four shifts per week. If you build your spreadsheet around a four shift operation and suddenly someone proposes a five shift arrangement, you are in hell.

By the time you recognize the signs, you are probably too late to avoid at least a taste of spreadsheet hell, but not too late to change plans before it gets highly problematic. Tabel 1 lists some of the warning signs.

Table 1: Top 5 Warning Signs of Spreadsheet Hell

| |
|---|
| When cell reference errors occur, especially in unexpected locations |
| When two numbers are supposed to agree and don't |
| When making a modest change, the spreadsheet grows significantly |
| You are no longer confident that you are getting right answers |
| You really wish you could start over |

The key is to see the point of diminishing returns ahead of time and address it then. All too often people reach the point of diminishing returns without budget or plan. That is they do not realize they are in a crisis until they are deeply in it.

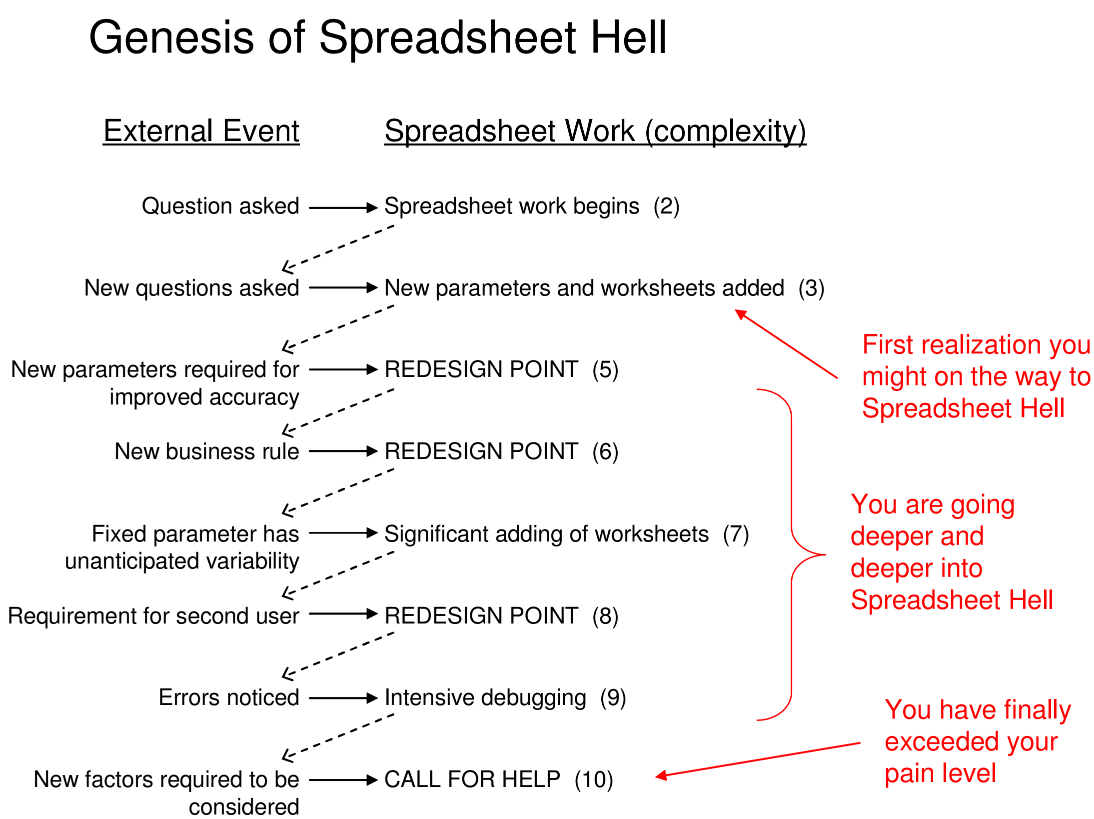
I'm in Hell … Now What?

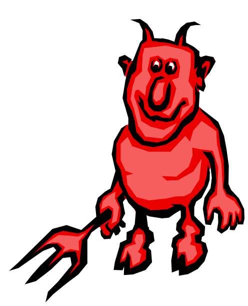
So you didn't see this coming until it was too late. What can you do? Start by recognizing where you are. The biggest asset you have is the experience in building the spreadsheet. You do understand the complexity, the issues and the need. Those elements of understanding are a huge part of the value you bring to the operation. Spreadsheet programming is probably not what management is paying you for anyway. They are paying for answers. You have the understanding of the problem and the skills to analyze it. It’s like you've been trying to build a house without power tools. Now you need a better tool.

Once you know where you are, move quickly. This situation is not going to get better on its own. Look at the questions you are being asked to solve and evaluate tools that answer those questions. And look for tools that appear to be able to answer questions that you haven't been asked yet, but can see coming.

And finally, add the tool or tools that are needed and resource it properly. You are involved in a business process, which, like any other, requires appropriate resources.

A useful analogy to spreadsheet hell is that it is similar to a step in the process of growing up. At the beginning, life is simple. As life becomes more complex over time, change is inevitable. What worked at one point in time is not as useful now. And that is the key to exiting spreadsheet hell. If you see it as a maturing business process, you are well on your way. Congratulations on graduation from spreadsheet hell!



**IC Production on 450-mm Wafers: Never Happen**
**Recent Survey of Semiconductor Industry Insiders Leads to Eye Opening Response**

June 20, 2007 (Pleasanton, CA) –Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, recently conducted a survey on equipment and process timing in the semiconductor industry. This survey was done in conjunction with its EquipmentFutures™ May 2007 forecast of equipment trends which is distributed by Strategic Marketing Associates (SMA – www.scfab.com).

Fifty percent or more of respondents expect to see the following manufacturing technologies in production between 2008 and 2010:

- Adaptive Test
- High K gate dielectrics
- Metal gates
- Equipment with energy saving "sleep" states

Between 2010 and 2012, 50% or more of respondents expect to see:

- 193 high index immersion lithography
- Wafer-level reliability testing
- Damascene gate formation

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

- EUV lithography
- Imprint lithography
- 450-mm wafers

Daren Dance, WWK's Vice-president of technology commented, "We were not surprised that the most frequent response to the question about 450-mm wafer timing was 2013 or beyond but we were surprised that 39% of respondents indicated that 450-mm wafers would never happen in production manufacturing. Thus, we expect that fabs can plan on at least 5 years, and probably more, life from their current investments in 300-mm manufacturing equipment."

The details behind this survey have been distributed to subscribers of EquipmentFutures™ and to survey respondents. EquipmentFutures™ is a unique series of equipment forecast that covers six individual semiconductor manufacturing equipment groupings. It takes both market research on semiconductor and equipment sales and semiconductor device end market demand into consideration. Each module contains information on unit volumes (conservative, median, and optimistic) as well as projected average selling price (ASP) on a quarterly basis for five years.

Strategic Marketing Associates provides the industry with comprehensive and accurate data about wafer fabs and summary information about key industry trends. SMA has developed a suite of fab information products including 'The Quarterly Spot Report' on Semiconductor Fab Products, 'International Wafer Fab News', 'Fab Expenditures: The Next 18 Months', the Fab Construction Monitor: The Next 18 Months', 'The 300mm Fab Report' and the newly introduced 'FabFutures' and 'Fab TimeLine'.

*ISSN 1094-9739*

## Wright Williams & Kelly, Inc. Examines Mask Defect Inspection Cost

*Image Qualification versus Direct Mask Inspection: And the Winner Is*

September 18, 2007 (Pleasanton, CA) – Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today that it has published a report examining the cost structures of competing, on-going, mask defect inspection strategies for 193nm scanners operating at the 65nm node. The report addresses litho cell availability, inspection costs, opportunity costs, and mask costs. The report shows when each strategy is more cost effective. The report can also be customized for specific assumption sets and the data can be provided in TWO COOL® format. TWO COOL® is the semiconductor industry's de facto standard for cost of ownership (COO) and overall equipment efficiency (OEE) modeling.

"With the cost of litho clusters well in excess of $20 million, it is critical that these bottleneck tools be highly utilized," states David Jimenez, President of WWK. "Inspection strategies dramatically impact equipment utilization and capital productivity. However, with masks having the potential to cost in excess of $100,000 each, it is also important to understand when your inspection strategy will require back up mask sets and how those decisions ultimately impact the bottom line."

For more information regarding the purchase of this report or customization options, including cycle time and work in process (WIP) impacts, contact WWK directly at 925-399-6246 or at info@wwk.com.