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APPLIED Co$t MODELING

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

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Calendar of Events

July 2008

15-17 **SEMICON West**
Moscone Center, San Francisco, CA

15-17 **Intersolar North America**
Moscone Center West, San Francisco, CA

17 **Understanding and Using Cost of Ownership workshop**
Marriott Hotel, San Francisco, CA

Sign up directly with WWK and receive a 20% discount

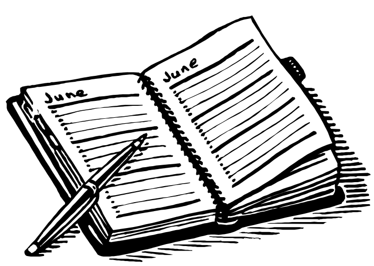
September 2008

1-5 **23rd Annual PVSEC**
Feria Valencia, Spain

9-11 **SEMICON Taiwan**
Taipei World Trade Center

October 2008

7-8 **Taiwan International Photovoltaic Forum & Exhibition**
Taipei World Trade Center



Reliability Compared with Other Disciplines

Reliability is a widely recognized and used discipline in developing, manufacturing, and servicing military and consumer products. Because of its broad use, it relates to many other disciplines within industry. In this chapter, we will compare reliability with related disciplines and identify their relationship, similarities, and differences.

5.1 Quality and Reliability

There is always a point of contention between quality advocates and reliability advocates. Is reliability part of quality or quality part of reliability? Experts have argued both ways for a long time. A simple answer is that if reliability is a customer requirement then reliability is a part of quality—one of the quality characteristics. However, quality definition has no time base. When you stretch the quality characteristic of performing intended functions forward in time then it becomes reliability, as shown in figure 5.1. In this regard, quality is a one-dimensional characteristic while reliability is a two-dimensional characteristic.

Quality relates to goodness of an item at a given instant. Most measures of quality are qualitative. Reliability relates to longevity. Most of the reliability metrics (see chapter 3) are quantitative.

5.2 Quality Control, Quality, and Reliability

Let us first understand the difference between Quality Control (QC) and quality. Quality is a characteristic, and QC is a process or method that helps to achieve and control the desired level of the quality characteristic.

QC assures that equipment designs (drawings) are converted to parts, components, subsystems, equipment, and systems, according to the specifications and without degrading the designed-in reliability. QC also assures that the manufacturing processes manufacture the products within the specified limits. In short, QC assures design and manufacturing quality.

Reliability assures that the proper design concepts and methodologies are used to achieve the desired reliability level.

Another contrasting point is that QC deals with the defective percentage mostly in the manufacturing stage, at a given point in time. Reliability deals with the behavior of failure rates throughout all periods of the equipment existence.

5.3 Safety and Reliability

Safety, as a characteristic of equipment, refers to being in a safe state and creating safe environments during manufacturing, installation, operation, and maintenance. This means there is no harm to anyone in any way (short term or long term) who is working with or in the vicinity of the equipment being manufactured, installed, operated, or maintained.

There is much similarity between reliability and safety. Both require a proactive approach and should be designed-in to achieve the desired level. Both deal with the equipment over all periods of the equipment existence. Although every reliability failure may not affect safety, any safety violation during the operation of equipment is considered as a failure within a reliability calculation. In this regard, safety is a subset of reliability, as shown in figure 5.1.

Because we now understand the safety factor, we can modify the formal definition of reliability (chapter 2) by adding a qualifier to read “performing intended functions for a specified time under the

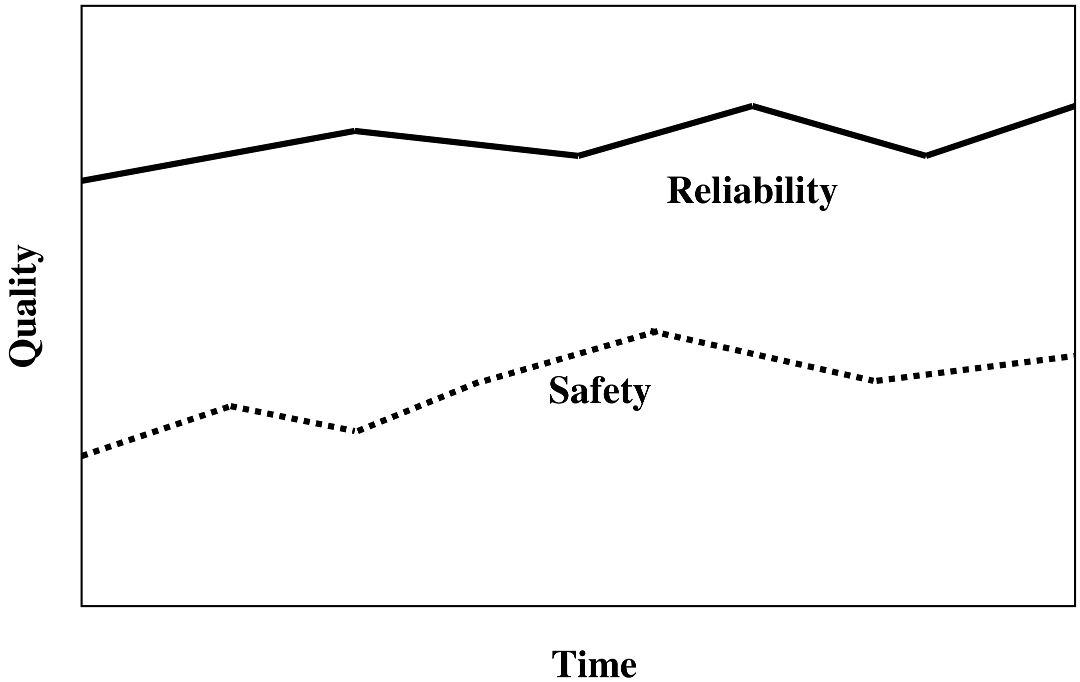


Figure 5.1 Relationship among Quality, Reliability, and Safety

stated conditions, safely." This modification links safety and reliability.

5.4 Maintainability and Reliability

There is no direct relationship between reliability and maintainability. Reliability deals with the operational longevity and failures of equipment, while maintainability deals with restoring equipment operation and the time it takes to restore it. However, both disciplines are complementary and both support high-level equipment performance metrics such as availability and Overall Equipment Efficiency (OEE) (see chapter 6).

Formally, maintainability is the probability that the equipment will be restored to a specific operational condition (able to perform its intended functions) within a specified period of time, when the maintenance is performed by personnel having specified skill levels and using prescribed procedures, resources, and tools. Maintenance can be either unscheduled or scheduled. One of the most popular measures of maintainability is Mean Time To Repair (MTTR), given by (equation 5.1):

$$Mean\,Time\,To\,Repair(MTTR) = \frac{total\ repair\ time}{number\ of\ repair\ events}$$

Repair time includes diagnosis, corrective actions, and verification tests, but not maintenance delays.

5.5 Availability and Reliability

Availability is a joint measure of reliability and maintainability. It is defined as the probability that the equipment will be in a condition to perform its intended functions when required. One popular formula for calculating availability is (equation 5.2):

$$Availability = \frac{MTBF}{MTBF + MTTR} - \frac{\%PM\ time}{100}$$

One of the most widely used availability metrics is percentage of uptime, which is defined as (equation 5.3):

$$\%Uptime = availability\ x\,100$$

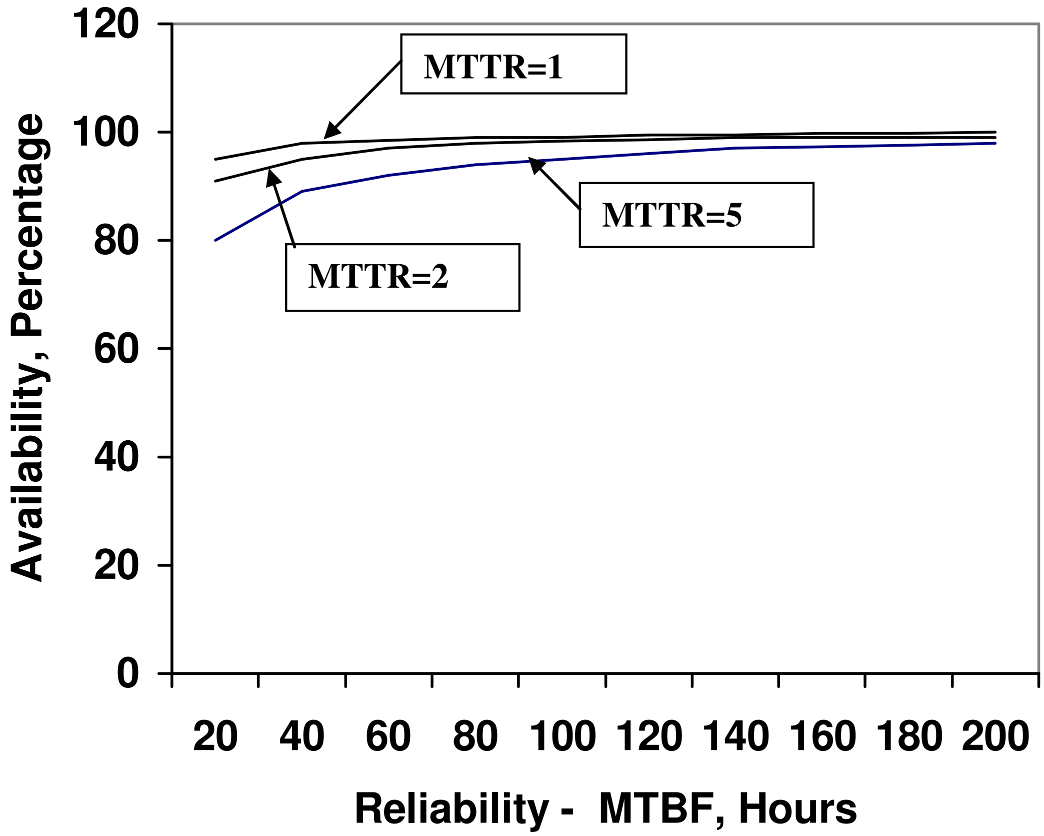


Figure 5.2 Relationships between Reliability (MTBF) and Availability

As evident by the above formulas, uptime (availability) is influenced both by reliability and by maintainability. Figure 5.2 shows a few typical graphs depicting this relationship. If reliability is high (high MTBF) then maintainability has very little effect on the availability. Maintainability and reliability have significant effect on availability when MTBF is low and MTTR is high.

Besides availability, there are other high-level equipment performance metrics that are related to and based on reliability. These metrics are presented in chapter 6.

5.6 Which Is More Important?

Which is more important: quality, reliability, safety, maintainability, or availability? The answer for this question is not a simple one. It depends on the situation. For example:

If defect-free equipment deliveries and consistence operations are necessary then quality and QC are important.

If the consequences of a failure are very high—either very costly to repair, lots of scrapped product units, or harmful to human beings—reliability and safety are most important. These situations demand an MTBF as large as possible.

If it is important to have equipment available whenever we want it, availability is most necessary. These situations require high MTBF and low MTTR.

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WWK Hosts Cost of Ownership Seminar at SEMICON West

WWK and SEMI Co-Sponsor Event for the 16th Consecutive Year

May 13, 2008 (Pleasanton, CA) – Wright Williams & Kelly, Inc. (WWK), the world's preeminent cost of ownership software and consulting services company, announced today that it will be presenting its highly acclaimed seminar, "Understanding and Using Cost of Ownership," during SEMICON West. "Understanding and Using Cost of Ownership" will be held at the San Francisco Marriott on Thursday, July 17 from 9am to 5pm. This seminar covers all aspects of Cost of Ownership (COO) and Overall Equipment Efficiency (OEE) from fundamentals to hands-on applications. Registration for this seminar can be done directly on the Semiconductor Equipment and Materials International (SEMI) web site at www.semi.org or by calling WWK directly.

There is limited seating available for this seminar, so please contact SEMI or WWK today to guarantee your place in this once-a-year event. It is expected that registration will close out shortly for this program. As an added benefit, WWK's software maintenance clients qualify for a 20% discount off the list price of the seminar if they book directly with WWK.

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).

In addition to its professional consulting and market research services, 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.

WWK Conducts 2nd Annual Semiconductor Manufacturing Technology Survey

Follow-up to 2007 Survey where 40% Said 450-mm Wafers will Never Happen

Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced the start of its 2008 survey on equipment and process timing in the semiconductor industry. The survey results will be consolidated and provided to all participants free of charge. The survey form can be downloaded at: http://www.wwk.com/2008survey.pdf.

Last year's survey showed that 50% 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

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 nearly 40% of respondents indicated that 450-mm wafers would never happen in production manufacturing. This year's survey will look to see if those opinions, and others, have changed."

Based on the results of the 2007 survey, WWK initiated a detailed cost study of projected 450-mm wafer costs compared to an equivalent 300-mm process. Details are found in "An Economic Comparison of 450-mm and 300-mm Wafer Fabs," Wright Williams & Kelly, Inc. 2008, http://wwk.com/pr450.html.

WWK Donates Advanced Simulation Software to University of Arkansas

It was announced that Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, has donated advanced modeling and simulation software licenses to the University of Arkansas, Fayetteville. The product, Factory Explorer®, is the high tech industry's only integrated capacity planning, financial analysis, and discrete-event simulation software solution. The licenses will be used for graduate teaching and research in the Department of Industrial Engineering.

According to University of Arkansas Associate Professor Dr. Scott J. Mason, "We are very excited to receive this gift. The contribution of Factory Explorer® is especially important to the Department of Industrial Engineering since it is state-of-the-art software currently used by many high tech manufacturers. Factory Explorer® will be used to support our ongoing research and teaching efforts in the modeling and analysis of semiconductor manufacturing systems. We thank WWK and look forward to making the most of these additional resources and to training our students on one of the premier modeling/analysis tools used in semiconductor manufacturing practice today."

"WWK believes that the value of academic and industrial cooperation serves both communities well," states David W. Jimenez, WWK's President. "We are thrilled to support the outstanding research of Dr. Mason in this important area of advanced semiconductor manufacturing."

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WWK Reexamines 450-mm Wafer Fab Economics

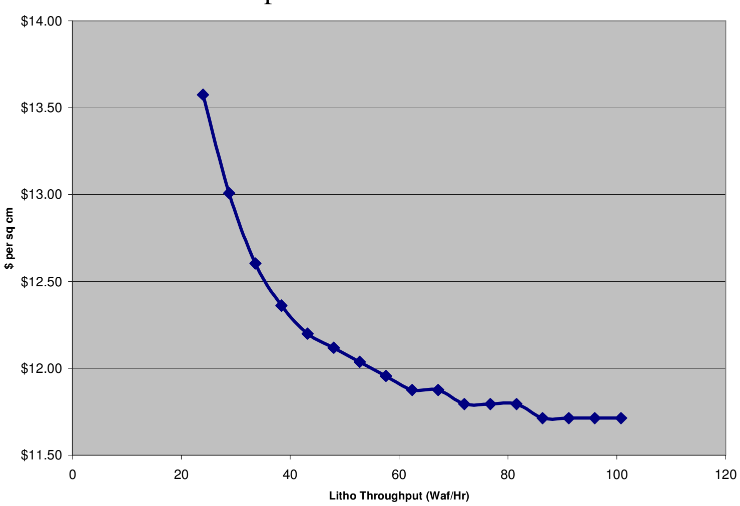
Addendum looks at sensitivity analyses for capacity, throughput, and silicon costs

Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced the availability of an addendum to its report examining the cost structures of 300-mm and 450-mm wafer fabs. The report can be ordered directly from WWK at http://www.wwk.com/450order.pdf and will come with both the original report and the addendum looking at sensitivity analyses for fab capacity, key equipment throughput, and raw wafer costs.

In April 2007, WWK conducted a survey of semiconductor industry professionals asking, among other things, about the expected arrival date of 450-mm wafers. The most common answer was 2013 or later, which was the last date specific choice. However, WWK was surprised when nearly 40% answered that 450-mm wafers would never happen. Subsequently, WWK looked closer at 450-mm wafers and semiconductor manufacturing economics. The findings of that study are presented in the report, “An Economic Comparison of 450-mm and 300-mm Fabs.” The 2008 follow up survey can be downloaded at http://www.wwk.com/2008survey.pdf. The survey results will be tabulated and provided to all participants free of charge.

“Given the historical framework of the introduction of 300-mm wafers and the dire impact that had on the supply base, it is easy to see why equipment companies are taking a hard line on who will pay for the next wafer size,” states Daren Dance, Vice President of Technology at WWK. “We have examined the issue of transitioning from 300-mm to 450-mm wafers from an unbiased perspective that is neither funded nor supported by suppliers, IDMs, or foundries. This report is the first independent examination of the economic and other driving factors that either support or refute the 450-mm move. Based on comments from readers of the original report, we examined additional key sensitivities to see under what conditions 450-mm might make sense.”

The following is an extract from WWK’s *Comparison of 450-mm and 300-mm Fabs: Sensitivity Addendum* illustrates the sensitivity of cost per square centimeter of a finished wafer to lithography throughput rates. Although with many semiconductor manufacturing tools throughput rate is not area dependent, lithography and ion implant are examples of manufacturing tools where the throughput rate is wafer area dependent.



450-mm Cost per sq cm v. Litho Throughput Rate

Since lithography equipment is the most expensive part of a fab investment and is often the fab bottleneck, we looked at litho throughput rates. The initial WWK assumption for litho throughput was based on an equivalent area to our assumption for a 300-mm system.

The left figure shows that even though finished wafer cost is significantly impacted by litho throughput rate, even a 450-mm litho throughput rate that is over 4 times the initial WWK assumption does not lower the finished wafer cost to the 300-mm level of $8.34 per sq cm.

Wright Williams & Kelly Releases Factory Commander® v3.2

Wright Williams & Kelly, Inc. (WWK) announced the latest release of its factory-level cost and resource evaluation software, Factory Commander® v3.2. Managers in the semiconductor, flat panel display, photovoltaic, storage, and other manufacturing and assembly industries use Factory Commander® to quickly and accurately evaluate their strategic and tactical options. Factory Commander®'s applications include capacity planning, capital budgeting, product costing, profitability analysis, and strategic planning.

New features in this release combine to provide an even greater ability to model real-world situations while maintaining traditional ease of use. Some of the key features include enhanced process and product modeling, the ability to specify time spans for unit starts (or outs) that differ from the modeling period, and enhanced import/export templates.

A new record type, process records, is now integrated into the modeling architecture. This allows the user to define processes which represent a unique process flow. Processes are now separate modeling entities from products. This feature enables the same process to be assigned to multiple products. The processes are now the entity defined by a series of process steps, as opposed to products, as was the case in prior Factory Commander® releases.

Another feature is the ability to specify the time span for production demand so that it differs (i.e., is smaller) than the modeling time period. For instance, the user can designate wafer starts on a weekly basis, as opposed to wafers per quarter or year. Unit starts can be defined in "per modeling period", "per month", "per week", and "per day". This feature allows data to be collected and used in the program that correspond to more familiar metrics used by production and business planning groups within the organization.

The native templates used to import and export data into/from Factory Commander® now include features enhancing their usability. The benefit is that the user can now edit templates without impacting the program's ability to read the template's data on import. For instance, rows or columns can be added and any information entered in those rows or columns, e.g. commentary, reminders, etc., will be ignored on import.

Factory Commander® is the best choice for your factory's cost/resource evaluations needs. Let Factory Commander® help you reduce your manufacturing costs and show you the way to increased profitability. For additional information contact Wright Williams & Kelly, Inc. at 925-399-6246.

The Toyota Production System Sanity Check[2]

Many semiconductor companies have instituted "lean" manufacturing. Perhaps you are already following the Toyota Production System without knowing it. Try taking the TPS test. Be sure to ask a few different fab people these questions. You may get some very different answers.

Questions

1) Do you know the theoretical minimum time to process a wafer?

2) Do you know exactly how many process steps are required to complete a wafer?

3) Is your actual manufacturing process time less than twice your theoretical minimum process time?

    a) Do you know the critical process step that constrains the throughput capacity of your fab?

    b) Is the uptime of the process equipment in that step predictable?

    c) Is there a fundamental reason that the manufacturing process time cannot approach the theoretical minimum process time in your fab?

4) Do you know the cost per wafer of each process step?

    a) Is your scrap rate less than 2 percent?

    b) Is your rework rate less than 2 percent?

5) Do you know exactly how many wafers are in your fab?

    a) How many are product wafers?

    b) How many are test wafers or process-monitor wafers?

    c) How many are engineering wafers?

    d) What is the ratio of product-wafer processing to non-product-wafer processing?

6) Were you able to rapidly identify and trace the latest drop in yield in your fab?

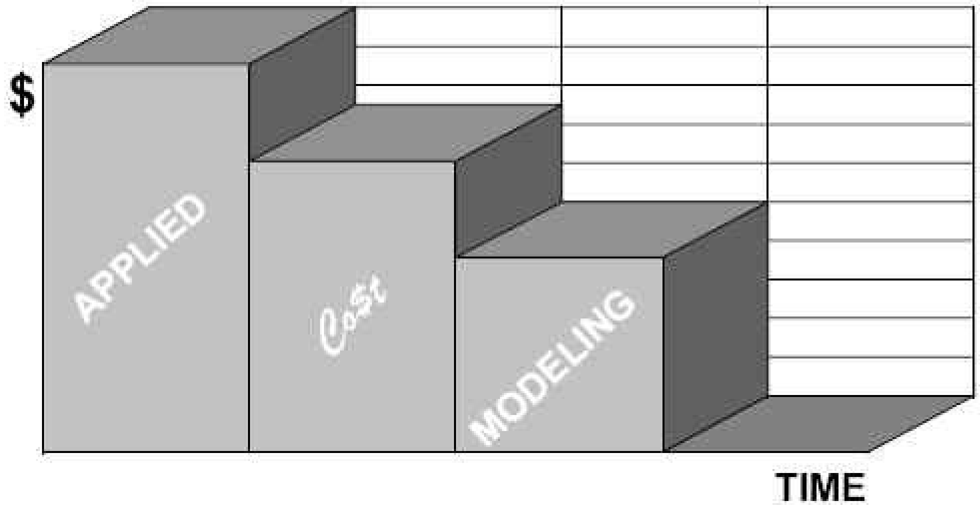
    a) Did you have enough data to empirically correlate the yield drop to a piece of equipment or specific process step?

    b) How do you know that the process equipment is operating within specifications?

7) Did everyone give you the same answers?

    a) Were they all in the fab today?

[2] Clayton M. Christensen, Steven King, Matt Verlinden, and Woodward Yang, *The New Economics of Semiconductor Manufacturing*, IEEE Spectrum, May 2008



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