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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 the first half of Chapter 8. We hope that you find the information in this series useful.

[Continued on Page 3]

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Calendar of Events

March 2009

17-19 SOLARCON China
Shanghai New Intl Expo Centre
Shanghai, China

29-30 SEMI North America Standards Meeting
Sheraton-San Jose Hotel
Milpitas, CA

April 2009

1-2 SEMI North America Standards Meeting
Sheraton-San Jose Hotel
Milpitas, CA

9-10 Global FPD Partners Conference
Sheraton Grande Tokyo Bay Hotel
Urayasu, Chiba, Japan

21-22 DOE Solid-State Lighting Manufacturing Workshop
Fairfax, VA

May 2009

11-13 Advanced Semiconductor Manufacturing Conference
Pullman Berlin Schweizerhof
Berlin, Germany

27-29 Intersolar
New Munich Trade Fair Center
Munich, Germany

Generic Reliability Improvement Process

In the last chapter, we described equipment and equipment program life cycle phases. In this chapter, we will study a generic Reliability Improvement Process (RIP) that encompasses all phases of the equipment program life cycle.

8.1 Reliability Improvement Process (RIP)

The Reliability Improvement Process (RIP) is a four-step and multiblock iterative process, as shown in figure 8.1. The four major steps are:

1. Know reliability goals and requirements
2. Design in reliability
3. Build in reliability
4. Manage reliability growth

The following sections describe these steps in detail. These four steps are essential to better equipment reliability. Granted that all the equipment programs do not go through all of the equipment life cycle phases described in chapter 7. Some of the activities of the RIP may not be performed. However, if an equipment manufacturer follows the four basic steps to better equipment reliability, there is a good chance that its equipment reliability will be higher than that of manufacturers who do not do so.

8.2 Know Goals and Requirements

If what is required is unknown, it probably will not be achieved. Therefore, the first step to better reliability is to know the reliability goals and requirements, whether you are a manufacturer or a customer. There is a distinction between goals and requirements. The goals are more the internally driven desires of an equipment manufacturer, which may not be met. Requirements, on the other hand, are more specific and are customer driven. Requirements are usually included as deliverables in contractual agreements. They are expected to be met. Goals are the starting point, but are modified to satisfy customer requirements early in the equipment life cycle. The reliability goals and requirements must be attainable, supportable, acceptable, and measurable.

If you are a manufacturer (supplier) of equipment, you need to:

- Understand the exact reliability requirements of your customer
- Be aware of the reliability level of your competitor's product
- Know what reliability level is required in the marketplace

Considering the above factors, set the reliability goals for the equipment line at the beginning of each equipment program.

If you are a customer, it is your responsibility to make sure your equipment supplier knows your exact requirements.

The goals or requirements should include the following:

1. Reliability level and metric (e.g., MTBF = 700 hours)
2. Time factor, such as the age of the equipment at which it should attain the reliability level (e.g., 4 months after installation)
3. Operational conditions, such as:

- Temperature and humidity (e.g., temperature range: 70 - 75ºF, humidity range: 40 - 50% RH)
- Duty cycle (e.g., twelve hours/day)
- Throughput rate (e.g., fifteen wafers/hour)

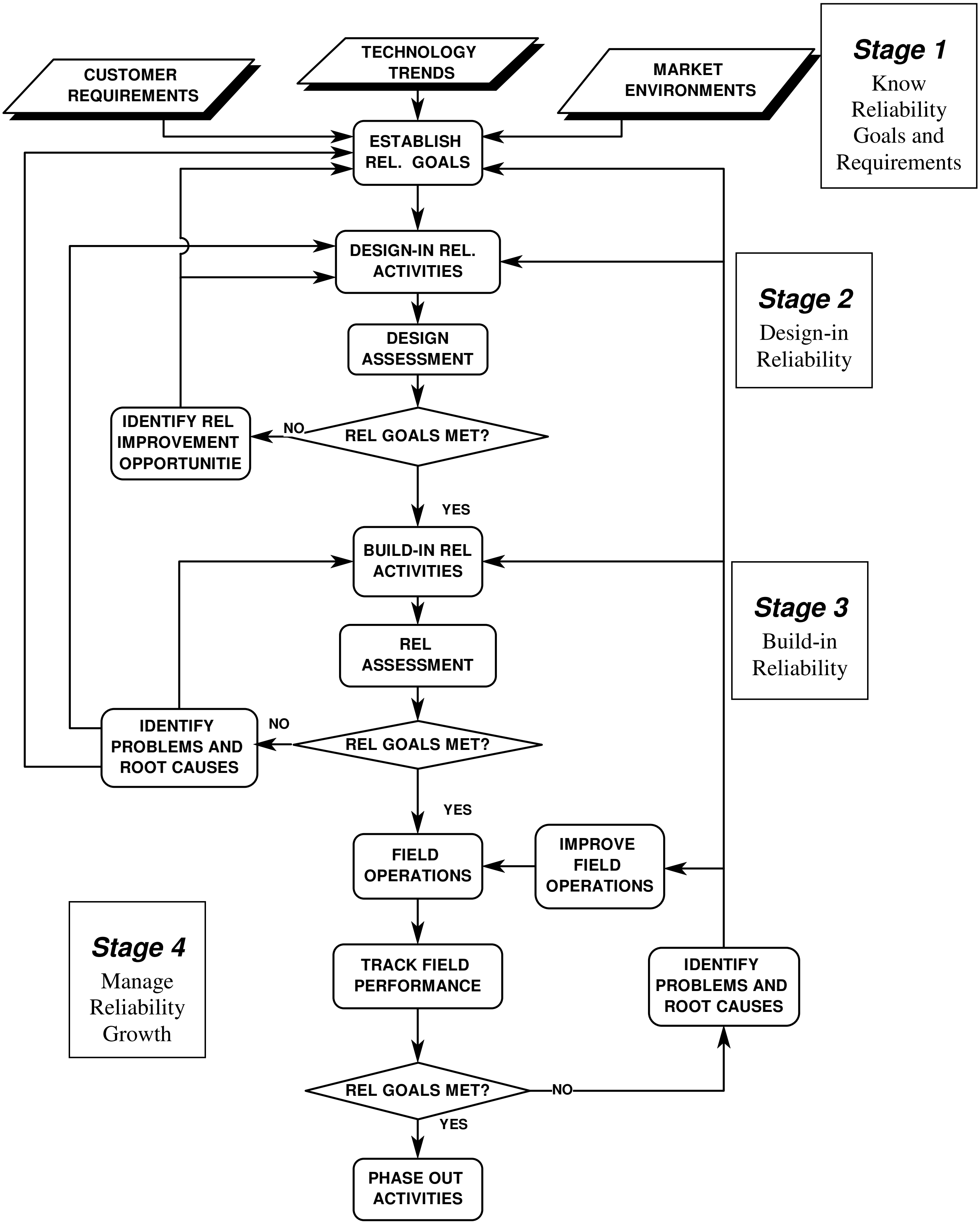

Figure 8.1 Generic Reliability Improvement Process

- Process to be used (e.g., high density plasma etch)
- Operator skill level (e.g., grade twelve or equivalent)
- Preventive maintenance policies to be followed (e.g., monthly PM policy described in the user's manual)

4. Shipping and installation limitations (e.g., to be shipped by air cushioned truck and installed by a special installation team)
5. Confidence level for the reliability metric (e.g., 90% confidence in the MTBF value)
6. Acceptable evidence for attaining the required reliability level (e.g., theoretical or calculated values, based on in-house test data, or based on field data)

<u>Goal Allocation</u>
Once the goals are known, the equipment manufacturer must break down the equipment and system-level goals into "bite-size" goals for software, subsystems, modules, and components. This makes it easy for subsystem, module, or component engineers to achieve their respective product goals.

The process of breaking down the equipment and system-level goals into the next levels of subgoals, based on some logical justification, is called apportionment, budgeting, or allocation. This process is just like breaking down division-level budgets into department-level budgets. Many methods are available. Some widely used ones are

- Equal allocation: Every lowest level component gets an equal share of the goal.
- AGREE allocation method: Weight factors based on the complexity and criticality of the components are added in the calculations. See reference 1 for details.

- ARINC allocation method: Weight factors are based on the inherent failure rate. See reference 1 for details.

8.3 Design-in Reliability
This is the most important and elaborate step to achieving better equipment reliability. To design-in reliability means to consider reliability improvement goals concurrently with other technical aspects at every activity of the design phase. Figure 8.2 depicts the process of design-in reliability. Six major blocks of the process are:

1. Use proper parts properly
2. Use proper design techniques
3. Design to minimize the effect of external factors
4. Avoid failures through scheduled maintenance
5. Hold design reviews
6. Assess the reliability of the design using the modeling techniques

Reference 2[2] contains a detailed description of each block. The following is a brief summary.

<u>Use Proper Parts Correctly</u>
The use of proper parts correctly is the most crucial block of the design-in reliability process. It consists of the following activities:

[2] SEMATECH, Design Practices For Higher Equipment Reliability - Guidebook, Technology Transfer #93041608A-GEN (Austin, TX: SEMATECH, Inc. 1993).

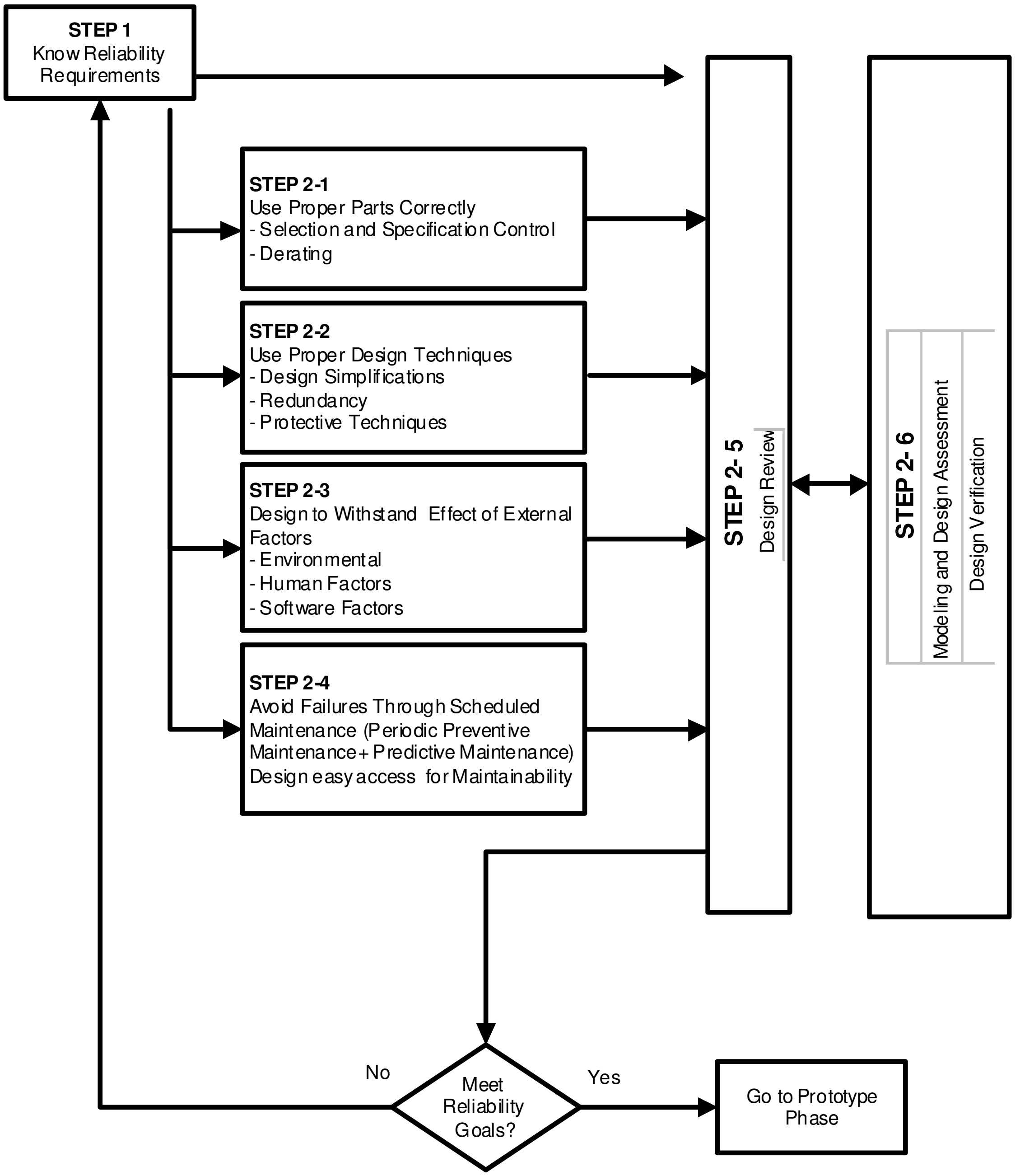

Figure 8.2 Process of Design-in Reliability

Part Selection: Before selecting any part and its supplier, determine the part type needed to perform the required functions and the environment in which it is expected to operate. The general rule for part selection is that, whenever possible, the designer should strive to use proven parts in the design and select a supplier who has proven historically to meet or exceed the part reliability requirements.

See chapter 12 for details on how to purchase reliable parts.

Part Specification: For each reliability sensitive part, its procurement specification should include:

- Details of the intended applications
- Reliability requirements of the intended applications
- Part screening procedure
- Part qualification procedure

Part Derating: Once the part is selected, perform an analysis to compare the expected stress level for the intended applications with those of the part's rated (capacity) stress level. A technique known as derating is used to improve the design reliability. In this technique, a part is selected so that it will operate at a less severe stress level than the level at which it is rated capable of operation. For example, if the expected power level is ten watts for a device, select the parts that are rated for significantly higher than ten watts of power. Table 8.1 contains suggested derating factors for various electronics components.

- Desired values are derived during the feasibility phase. They are used to compare with either theoretical or observed values during the rest of the life cycle phases.
- The theoretical values are derived during the design phase. They are used to compare either with goals or with observed values during the rest of the life cycle phases.
- The goals (desired values) are not derived during the production phase.

Use Proper Design Techniques

Use of proper design techniques is another crucial block of the design-in reliability process. It consists of the following activities:

Design Simplification: Anything that can be done to reduce the complexity of the design will, as a general rule, improve reliability. If a part is not required, eliminate it from the design. Wherever possible, reduce the number of parts by combining functions.

Redundancy: This is one of the most popular methods used in design to achieve the needed level of reliability. Redundancy is the provision of more than one part for accomplishing a given function so that all parts must fail before causing a system failure. Redundancy, therefore, permits a system to operate even though some parts have failed, thus increasing system reliability.

For example, if we have a simple system consisting of two identical redundant (parallel) parts, the system MTBF will be 1.5 times that of the individual part MTBF (see chapter 4).

Protective technique: This technique includes an element in the design to prevent a failed part or malfunction from causing further damage to other parts. The following are some of the popular protective techniques used in equipment designs:

- Fuses or circuit breakers to sense excessive current drain and to cut off power to prevent further damage
- Thermostats to sense over-temperature conditions and shut down the part or system until the temperature returns to normal
- Mechanical stops to prevent mechanical parts from traveling beyond their limits
- Pressure regulators and accumulators to prevents pressure surges
- Interlock to prevent inadvertent operations

Design to Withstand Effect of External Factors

The operating environment might be neither forgiving nor understanding. It methodically surrounds and affects every part of a system. If a part cannot sustain the effects of an expected environment, then reliability suffers. First, the equipment manufacturer must understand the operating environment and its potential effects. Then it must select

Component	Stress category	Derating factor
Capacitors, general	Voltage	0.5
Capacitors, ceramic	Voltage	0.5 at < 85°C
		0.3 at < 125°C
Capacitors, supermetallized, plastic film, any tantalum	Voltage	0.5 at < 85°C
	Temperature	Less than 85°C
Capacitors, glass dielectric, fixed mica	Voltage	0.5 at < 85°C
	Temperature	Less than 85°C
Connectors	Current	0.5
	Voltage	0.5
	Temperature	Less than 125°C
Quartz crystals	Power	0.25
Diodes	Voltage	0.75
	Current	0.5
EMI & RFI filters	Voltage	0.5
	Current	0.75
Fuses	Current	0.7 at < 25°C
		0.5 at > 25°C
Integrated circuits (all kinds)	Voltage	0.7
	Current	0.8
	Power	0.75
Resistors (all kinds)	Voltage	0.8
	Power	0.5
Thermistors	Power	0.5
Relays and switches	Current	0.75 for resistive load
		0.4 for inductive load
		0.2 for motors
		0.1 for filament
Transistors	Breakdown voltage	0.75
	Junction temperature	Less than 105°C
Wires and cables	Current	0.6

Table 8.1 Derating Factors for Electronics Components

Note: Above factors were derived from reference 3[3].

designs and materials that can withstand these effects or provide methods to alter and control environmental conditions within acceptable limits.

The equipment design engineers must consider the following external factors affecting reliability:

- High temperature
- Shock and vibration
- Moisture
- High vacuum
- Explosion
- Electromagnetic compatibility
- Human use
- Software design

[3] MIL-STD-1574A, Electronic Parts, Material, and Processes for Space Launch Vehicles, USAF. 1987.

Avoid Failures through Scheduled Maintenance

One way to improve reliability is to minimize the number of failures that occur during operation. This can be achieved in two ways:

1. Select parts that fail less frequently
2. Replace a part before its expected failure time

The latter method is known as Scheduled Maintenance (SM). This technique is used when it is not feasible to use a part that fails less frequently. If such a situation is properly incorporated into the design phase, it can be avoided through one of the following SM techniques.

Periodic preventive maintenance: This is a fixed-period maintenance procedure in which the parts that are partially worn out, aged, out-of-adjustment, or contaminated are replaced, adjusted, or cleaned before they are expected to stop functioning. This way, the system failures are forestalled during the system operations, thus reducing the average failure rate.

Predictive maintenance: This is a condition-driven and/or data-driven scheduled preventive maintenance program. Instead of relying on fixed-period-of-life units to schedule maintenance activities, predictive maintenance uses direct monitoring of appropriate indicators and/or data to determine the proper time to perform the required maintenance activities.

Design Review

Design reviews are an essential element of the design-in reliability process. The main purposes of a design review are to ensure that:

- Customer requirements are satisfied
- The design has been studied to identify possible problems
- The alternatives have been considered before selecting a design
- All necessary improvements are based on cost and reliability trade-off studies

Conduct design reviews on a regular basis, from the design feasibility study through the pilot production phase. An effective design review team should have representation from each functional area involved in developing the equipment. Table 8.2 contains the makeup of an effective design review team and the responsibility of each member. To facilitate the design review process, use the appropriate system-level or part-level checklists given in table 8.3 or table 8.4.

Reliability Assessment of the Design

Once the equipment design starts taking shape, it must be assessed to determine its reliability level and the system-level effect of the failure rate of each part. Modeling techniques determine analytical value of the reliability level. Failure Mode and Effects Analysis (FMEA) technique determines and alleviates the system-level effect of part failures. There are many commercially available software packages that perform modeling and FMEA.

Design Verification Test

Once design is firmed, conduct a design verification test to determine the reliability level under the expected use conditions (see chapter 11). If the observed reliability level is lower than the expected, identify areas for improvement and implement corrective actions (design changes).

Sections 8.4 through 8.9 will be published in the next edition of Applied Cost Modeling.

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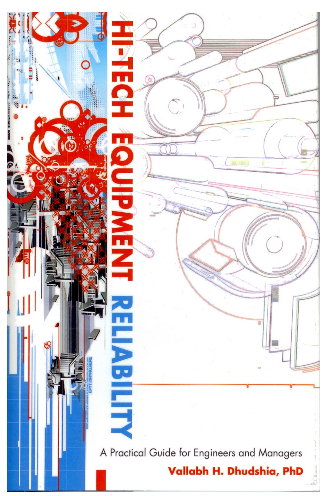
Member	Responsibility
Team Leader (Preferred: Design or Reliability Engineering Manager)	Coordinate and conduct meeting; issue minutes of the meeting and interim and final reports
Design Engineer (Mechanical, Electrical, Industrial)	Prepare and present design and substantiate decisions with data from tests of calculations
Reliability Engineer	Evaluate design for optimum reliability, consistence with the reliability goals
Service (Field) Engineer/Maintainability Engineer	Ensure that installation, maintenance, and operations requirements are considered in the design
Procurement Representative	Ensure that acceptable parts and material are available that meet cost and delivery requirements
Quality Engineer	Ensure that inspection and control functions and test can be carried out efficiently
Material Specialist	Ensure that the selected material will perform as required
Process Engineer	Ensure that the hardware and software is capable of meeting process requirements
Software Engineer	Ensure that hardware and software are compatible and optimize reliability
Safety Engineer	Ensure that safety concerns are addressed
Tool Engineer	Evaluate design in terms of the tooling costs required to satisfy tolerance and functional requirements
Packaging and Shipping Specialist	Ensure that the product is capable of being handled and shipped without damage
Marketing Representative	Ensure that the customers requirements are met
Toughest Customer (optional)	Provide ultimate user's concerns

Table 8.2 Design Review Team Members and Their Responsibilities



#	Item	Status
1 2	Design criteria for system level reliability Reliability test plan for qualification and acceptance tests	
3 4 5	Maintenance criteria and procedures Simple design with minimum number of parts Unified system design rather than an accumulation of parts	
6 7 8	Using high-reliability parts PM procedure at system level PM policy for high failure rate parts	
9	Parts requiring special procurement, testing, and handling	
10 11	Use of redundancy for critical parts Indicators for critical functions	
12	Using test data to remove design inadequacies	
13 14 15	Minimum adjustments and accessibility to adjustments Minimum differences between prototype and production configurations Safety requirements	
16 17	Embedded software integration User interfaces	

Table 8.3 System Level Checklist for Design Review Team

#	Item	Status
1 2	Part compatibility with the system Part Requirements: ▪ Reliability Level ▪ Reliability test ▪ MTTR ▪ Stress level ▪ Process capacity and accuracy requirements for process sensitive parts	
3	Standard parts with proven high reliability	
4 5	Actually observed reliability (MTBF) in field Self life	
6	PM period, if applicable	
7 8 9	Accessibility for repair and/or replacement Derating factors Safety requirements	
10 11	Effect on system operations Inherent failure modes and their failure rates	

Table 8.4 Part Level Checklist for Design Review Team

Wright Williams & Kelly, Inc. Conducts 3rd Annual Semiconductor Manufacturing Technology Survey

Follow-Up to 2008 Survey Where Over 50% Said 450mm Wafers Will Never Happen

Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today the start of its 2009 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/2009survey.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

By 2012, respondents expect to see:

- 193 high index immersion lithography
- Imprint lithography
- Wafer-level reliability testing
- 300mm whole wafer testing

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

- Direct write
- EUV lithography
- Directed Self Assembly Nano-resists

Daren Dance, WWK's Vice President of Technology, commented, "We were not surprised in 2007 that the most frequent response to the question about 450mm wafer timing was 2013 or beyond but we were surprised that in 2008 56% of respondents indicated that 450mm 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 450mm wafer costs compared to an equivalent 300mm process. Details are found in "An Economic Comparison of 450mm and 300mm Wafer Fabs," Wright Williams & Kelly, Inc. 2008, **http://www.wwk.com/reports.html**.

Wright Williams & Kelly, Inc. Lowers Cost of Ownership Software License Fees

Reduces Licensing of TWO COOL® from 10 Seats to 1, Includes Training

Wright Williams & Kelly, Inc. (WWK), the world's experts in the application of cost of ownership (COO) for manufacturing environments, announced a reduction in its entry-level pricing through the creation of a new 1-seat license. Previously, TWO COOL®, WWK's flagship COO and overall equipment efficiency (OEE) software, was licensed with a minimum of 10 seats.

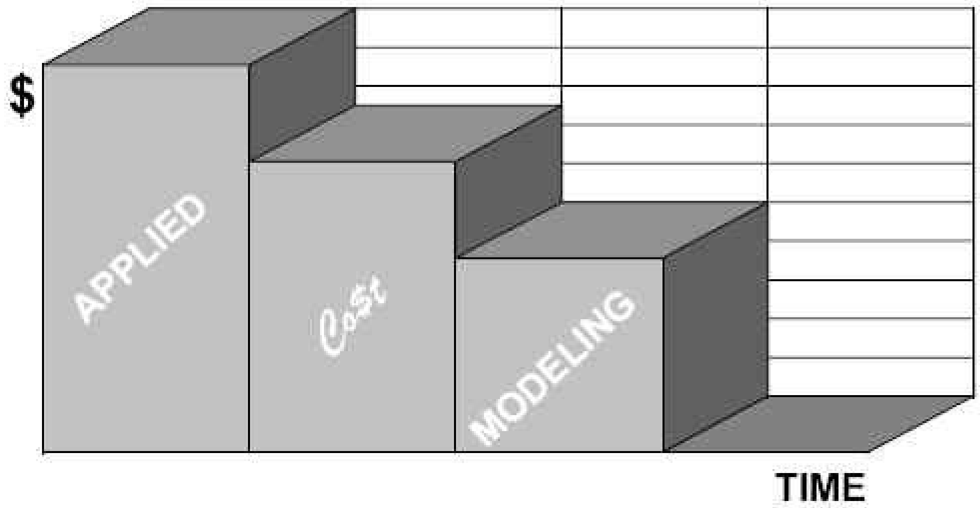
"It has been over a decade since we offered a 1-seat license to TWO COOL®," stated David Jimenez, WWK's President. "Capex reductions are negatively impacting the supplier side of our client base. However, this is the ideal time for our clients to invest in improving their cost competitiveness and WWK is dedicated to helping them achieve these goals with the smallest cash outlay possible."

Through the end of May 2009, WWK is offering a 1-seat license for $4,995; included in that price is free attendance to the training class "Understanding and Using Cost of Ownership" which will be held at SEMICON West/InterSolar 2009 on July 16 at the San Francisco Marriott. Further, WWK will provide a 100% credit of the 1-seat license price against any larger license through the end of 2009. Call 1-800-WWK-9744 (+1 925-399-6246 outside the US) for more information or a price quotation.

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.

POWERED BY TWO COOL®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