APPLIED Co$t MODELING

Information Exchange For Your Application & Use of Cost Modeling

Volume 14. Issue 1

Inside

Fall 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 in 2008) 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 second 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

January 2008

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

16-18 **Strategy Materials Conference (SMC)**
Half Moon Bay, California

30-1 **SEMICON Korea**
Convention and Exhibition Center (COEX)
Seoul, Korea

February 2008

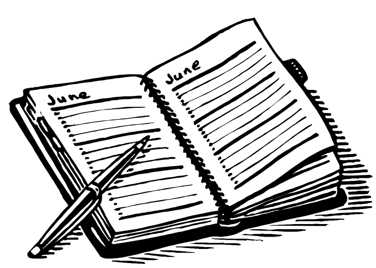
3-7 **IEEE International Solid-State Circuits Conference**
San Francisco Marriott
San Francisco, CA

March 2008

2-4 **Industry Strategy Symposium (ISS) Europe**
The Westin Dragonara Resort, Malta

11-13 **FPD China**
Shanghai International Exhibition Center
Shanghai, China

18-20 **SEMICON China**
Shanghai International Exhibition Center
Shanghai, China



Reliability Metrics

3.5 Relationship among the Reliability Metrics and Their Applications

Figure 3.6 shows all the most commonly used terms for reliability metrics and their applications. The reliability metrics can be converted from one category to another. For example, if we know MTBF, we can convert it to failures per 1,000 hours. Applications of the metrics can neither be converted from one to another nor mixed. However, they can be compared (for example, goal value versus observed values). Figure 3.6 shows these relationships.

When to derive the categories of application and when to use them for a comparison is explained in chapter 7.

3.6 Confidence Limit Calculations

When we deal with reliability metrics, either analytical or observed, we always face a

Reliability Terms

Reliability Metrics			
Probabilistic	**Mean Life**	**Normalized**	**Percentage**
Pr[T>1000Hr] =0.95 Pr[S]=0.80	MTBF MCBF MWBF	Failures/Million Cycles UM's/Million Hrs.	% Failed % Survived
Can be converted from one category to other Categories			

Applications of Reliability Metrics		
Desired Values	**Theoretical Values**	**Observed Values**
Goals Requirements Design Specifications Allocations Budget Apportionment Warranty	Calculated Inherent Expected Predicted	Observed Adjusted Confidence Limit
Cannot be converted from one category to other Categories **Can be Compared with other Categories**		

Figure 3.6 Reliability Metrics and Their Applications

ISSN 1094-9739

question: how much confidence do we have in the result? It varies depending upon the type of theoretical calculations made (to derive theoretical values) or number of failures observed and amount of time (or other measures of life) contained within the observation period. The confidence is expressed by calculating confidence limits of the calculated or observed values. Generally we are interested in lower confidence limit. Therefore, the calculation methods shown in the next section show lower confidence limit calculations only. Similar methodology is used to calculate upper confidence limits.

Confidence Limit Calculations for Theoretical Values

To calculate the confidence limit, we must have an underlying probability distribution for the calculated values. The underlying distribution depends upon the distribution of the MTBF or other values of the parts used in the calculations. Applying a law of large numbers, this distribution could be a normal distribution with a mean of the calculated values (μ) for the reliability metric under consideration and their standard deviation (σ). In such cases, use the formulae given in table 3.2 to calculate the lower confidence limit.

Confidence Limit	Formula Used
70 % Lower Confidence Limit	$\mu - 0.525\sigma$
80 % Lower Confidence Limit	$\mu - 0.842\sigma$
80 % Lower Confidence Limit	$\mu - 1.282\sigma$
95 % Lower Confidence Limit	$\mu - 1.645\sigma$

Table 3.2 Formulas for Calculating Lower Confidence Limit of Theoretical Values

For example, if μ and σ of the calculated MTBF values are 500 hours and 100 respectively, then 80% lower confidence limit for calculated MTBF = 500-0.842 x 100 = 415.8 hours.

Confidence Limit Calculations for Observed Values

Equation 3.1 for reliability metrics provides single-value estimates for the observed performance. The lower confidence limit for any observed reliability metric (MTBF, MWPF, MCBF, etc.) depends upon number of failures observed during the observation period. It is calculated using the following formula (equation 3.6):

$$P\%\ lower\ confidence\ limit\ for\ the\ observed\ metric = (observed\ value) x K$$

WHERE:

P% = Desired confidence level

Observed value = MTBF, MCBF, MWBF, etc. calculated based on the number of life units in the selected period and number of failures observed.

K = Appropriate multiplier, from table 3.3

The most commonly used confidence limit values are between 80% to 95% confidence levels. See Table 3.3 for the multiplier factor K values for failure truncated observation period (data taking is terminated after the nth failures). For time/cycle truncated or fixed length observation period, use table 11.4.

Number of Failures	80% confidence	90% confidence	95% confidence
1	.621	.434	.334
2	.668	.514	.422
3	.701	.564	.477
4	.725	.599	.516
5	.744	.626	.546
10	.799	.704	.637
15	.828	.745	.685
20	.846	.772	.717
30	.870	.806	.759

Table 3.3 Multiplier Factors K for Calculating Lower Confidence Limit of Observed Values

EXAMPLE:

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

Observed MTBF = 10,000/3 = 3,333 hours

K factor for 3 failures and 80% confidence level is 0.701 from table 3.3

Therefore, using equation 3.6

80% Lower confidence limit for the observed MTBF = 3,333 x 0.701 = 2,336 hours

3.7 Precise Use of the Reliability Metrics

We need the following items to define, fully and precisely, the reliability level of a real-life situation.

- Appropriate application (e.g., goal)
- Appropriate reliability metric (e.g. ,MTBF)
- Appropriate numerical value (e.g., 5,000)
- Appropriate unit for the metric (e.g., hours)
- Appropriate set of intended functions (e.g., metal etch process)
- Age of the equipment when the metric and value apply (e.g., two months after installation)
- Appropriate set of operational conditions (e.g., clean room environment)
- Appropriate confidence level (e.g., 80%) for confidence limit values.

EXAMPLES:

- Goal MTBF of 5,000 hours two months after installation, when used as metal etcher in clean-room environment.
- Part count calculations for poly etcher model E3000 shows inherent failure rate of 2.00 failures per 1,000 hours (MTBF = 500 hours) under the assumptions listed (need to have a list of all assumptions used in the calculations, such as operating conditions, part functions, etc.). Assuming σ = 100, 80% lower confidence limit for the calculated MTBF = 415.8 hours
- Observed MCBF = 20,000 cycles. When the facility-related failures are discounted, the adjusted MCBF =

30,000 cycles. 90 % lower confidence limit MCBF = 21,030 cycles (based on three equipment failures). Equipment is six months old and used as an oxide etcher.

- Predicted failure rate of 0.005 failures per 1,000 hours at maturity.

3.8 Standardization of the Reliability Metrics

As we see in this chapter, a multitude of terms exist for reliability metrics and their applications. To focus on the important ones, some industrial sectors have started standardizing definitions for the manufacturing equipment reliability metrics. A typical example is SEMI specification SEMI E10-0304[E], reference 1, which was developed by Semiconductor Equipment and Materials International (SEMI) to track reliability performance of the semiconductor manufacturing equipment.

SEMI Specification SEMI E10

To create synergy between semiconductor equipment suppliers and users, they must work together for mutual gains, understand reliability, availability, and maintainability (RAM) expectations of each other, and speak the same language when talking about equipment RAM metrics. SEMI E10 Specification provides this language (a common basis for communication between users and suppliers of semiconductor manufacturing equipment) by providing specifications for measuring reliability, availability (defined in chapter 5), and maintainability (also defined in chapter 5) RAM metrics of equipment in manufacturing environments. For equipment suppliers, SEMI E10 RAM metrics are useful at each product life cycle phase, from early equipment design and development through production. From equipment users point of view, SEMI E10 provides an industry-wide and company-wide uniform specification to collect, analyze, track, compare (machine to machine, wafer fab to wafer fab, and industry-wide), and report equipment RAM data. Accurate data collection of time allocation in each state is essential for calculating accurate RAM metrics. Automation efforts to collect the data are also based on SEMI E10 definitions and formulae. Both Cost of Ownership (COO) and factory capacity analyses use SEMI E10 RAM metrics. They also provide a basis for specifying reliability performance in equipment purchase order agreements. The long-term benefits of SEMI E10's international acceptance and use will improve relationships between users and suppliers of semiconductor manufacturing equipment that will stimulate a spirit of cooperation and partnership, promoting further improvements in equipment performance. These will lead to greater business success for both users and suppliers.

A task force (consisting of semiconductor manufacturing equipment suppliers and users) developed the specification under the SEMI Metrics Committee. The SEMI E10 was issued in 1986 as a guideline and then revised several times. With a revision in 1996, SEMI E10 became a SEMI standard and SEMI specification in 2000. See reference 1 for the latest revision of SEMI E10 (SEMI E10-0304[E]).

The SEMI E10-0304[E] is very widely used in the semiconductor manufacturing equipment industry. It has become a standard for tracking performance of the semiconductor manufacturing equipment and a benchmark for other industries.

Key Elements of SEMI E10

Two key elements of SEMI E10 are (i) events, scheduled, unscheduled, or nonscheduled, that stop equipment from performing its intended functions, and (ii) arrival and departure times for the events.

Events are categorized as scheduled or unscheduled. Unscheduled events are called failures. SEMI E10-0304^E defines the failure events as any unscheduled downtime event that changes the equipment to a condition where it cannot perform its intended function. Any part failure, software or process recipe problem, facility or utility supply malfunction, or human error could cause the failure. If a failure is solely caused by the equipment, it is called an equipment-related failure (e.g., E-failure).

EXAMPLES:

- Mean Productive Time Between Failures ($MTBF_p$)
- Mean Productive Time Between E-Failures ($E\text{-}MTBF_p$)
- Mean Wafer Between Failures (MWBF)
- Mean Cycles Between E-Failures (E-MCBF)

Use equation 3.1 to calculate a numerical value of any reliability metrics of SEMI E10-0304^E.

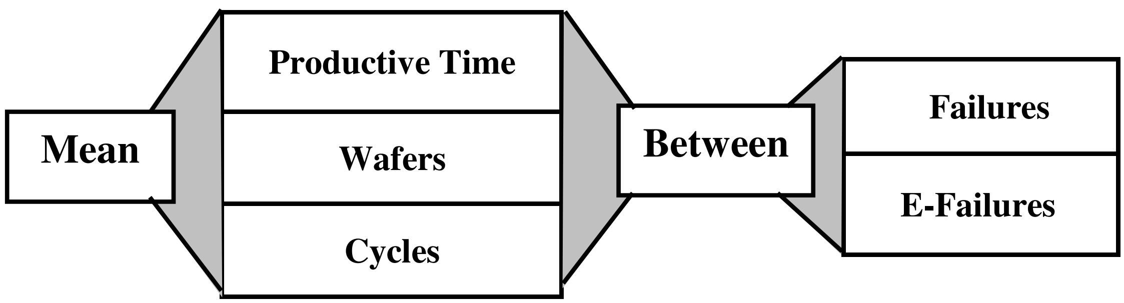


Figure 3.7 Algorithm for SEMI E10-0304^E Reliability Metrics

SEMI E10-0304^E uses the arrival and departure times of the scheduled, unscheduled, or nonscheduled events to break down total calendar time into various time blocks as shown in Figure 3.7. These time blocks are defined as equipment states and become the basis for equipment reliability, availability, and maintainability metric calculations.

Reliability Metrics of SEMI E10-0304^E

To make a required reliability metric, suitable to a given situation and compliant to SEMI E10 definitions, the algorithm given in figure 3.1 is modified as shown in figure 3.8. Use this algorithm to make the required metric. Use the word mean, select appropriate measure of life, use the word between, and select the desired event.

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).

[Look for installment 5 (chapter 4) in the fall edition of Applied Cost Modeling]

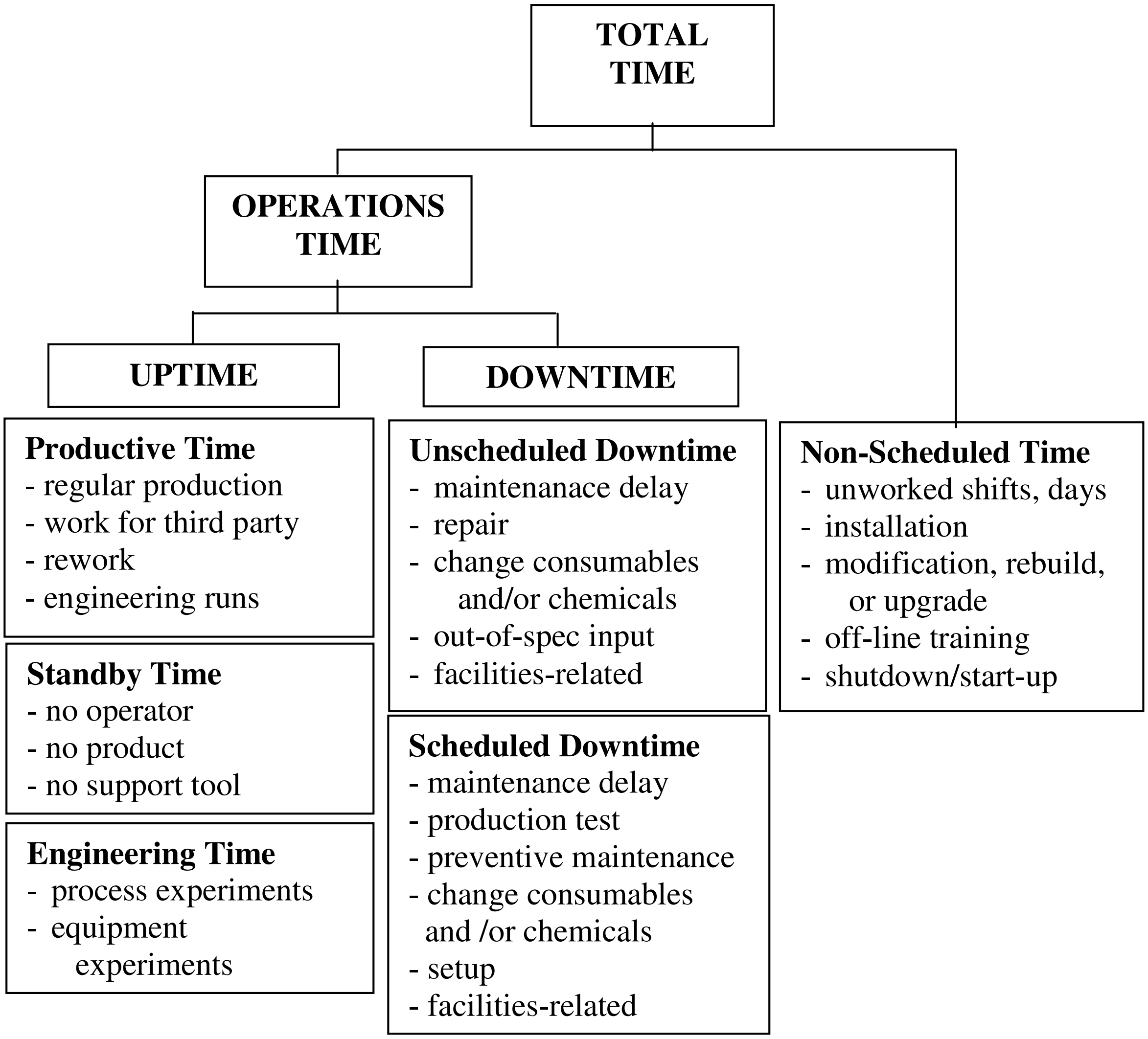


Figure 3.8 Equipment States and Time Breakdown of SEMI E10-0304[E]

WWK Reliability Related Services

"Reliability is one of the basic equipment performance characteristic. It is a life longevity measure of the failure-free operation period of any equipment. Formally, reliability is the probability of equipment performing its intended functions for a specified time under the stated operational conditions[2]." Another way to define equipment reliability is quality over time.

WWK offers a complete range of reliability related consulting services. Following are some of the questions that WWK has addressed:

- How reliable is my product?
- How would improving equipment reliability impact my costs? My customer's costs?
- What are the key causes of machine failures and how can I eliminate them?
- How can I implement an ISO 9001 compliant quality management system (QMS)?
- How does variance in performance impact my products and processes?
- How does incoming parts quality impact my products and processes?
- How do I design-in reliability?

Figure 1 illustrates some of the components of reliability that WWK considers.

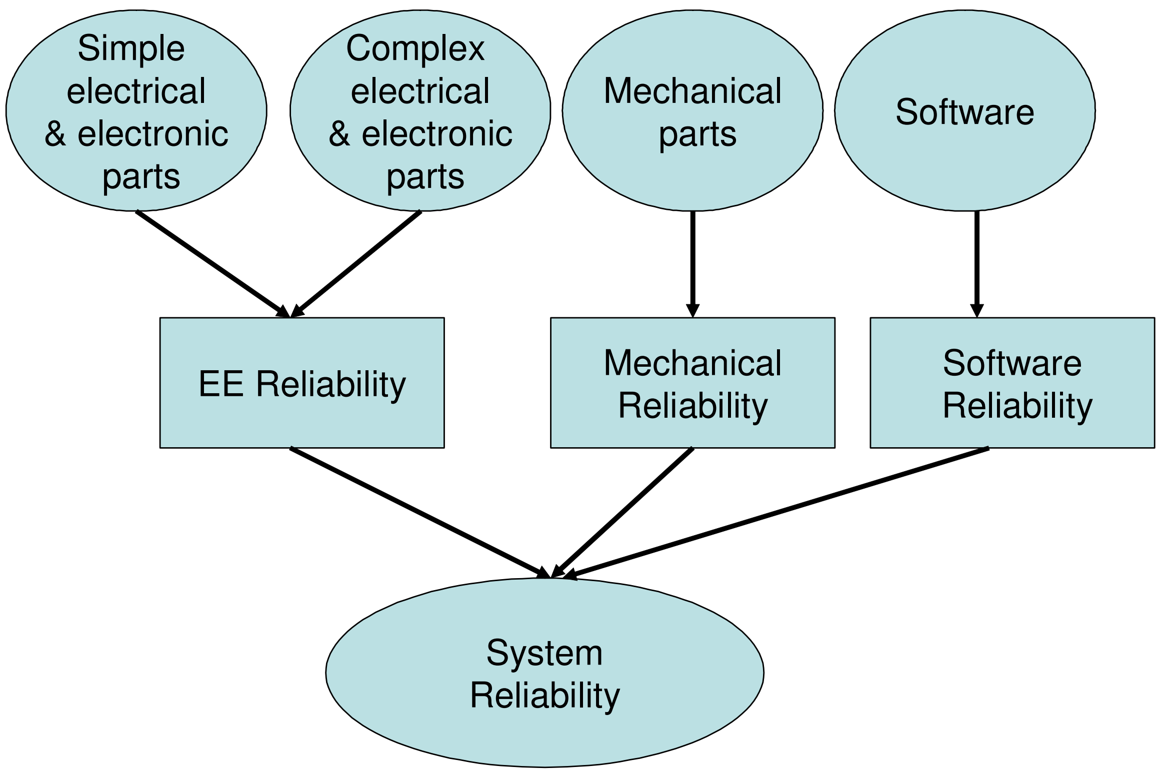


Figure 1: Reliability Components

[2] Vallabh Dhudshia, "Equipment Performance Metrics, Their Relationship and Hierarchy," *Applied Cost Modeling*, Winter 2004.

WWK is please to have a joint affiliation with Dr. Vallabh Dhudshia. 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 also served on the Board of Examiners for the 2007 Malcolm Baldrige National Quality Award

The following table describes the reliability course that Dr. Dhudshia is teaching in affiliation with WWK.

Module	Title	Description
1	Equipment RAMP: Basics and Metrics	A high-level overview of equipment reliability, availability, maintainability, and productivity (RAMP) disciplines. It contains basic concepts, definations, terminolgies, metrics, and their interdependancies and hierarchy. The module is designed to teach the essentials of RAMP desciplines without delving deeply into mathematical theory.
2	Equipment RAM Metrics Standard - SEMI E10	An in-depth presentation of SEMI E10. It contains history and background of the specification, basic definations, terminologies, and formulas used to calcualte RAM metrics. It also contains practical examples of SEMI E10 metrics calculations in a real life situation. This module is designed for anyone assessing manufacturing equipment reliability using SEMI E10 methodology.
3	Equipment Productivity Metrics Standard - SEMI E79	An in-depth presentation of SEMI E79 Standard. This module contains history and background of the standard, basic definitions, terminologies, and formulas for calculating manufacturing equipment productivity (Overall Equipment Efficiency – OEE). It also contains practical examples of SEMI E79 Standard OEE metrics calculations in a real life situation. This module is designed for anyone assessing manufacturing equipment productivity (OEE) using SEMI E79 methodology
4	Equipment RAMP Improvement Process and Organization	A generic equipment RAMP performance improvement process, four-steps to better RAMP throughout the equipment life-cycle phases, reliability testing, buying components and sub-systems for better RAM performance, RAM organization, and goodness assessment of the RAM improvement programs. This module is designed for anyone interestred in improving RAMP performance or organizing an effective RAMP assurance group

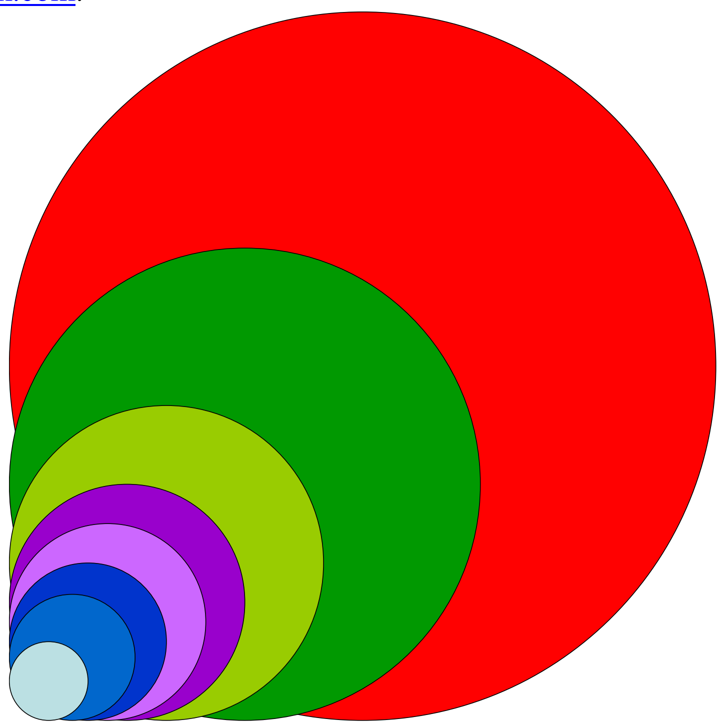
Further information on WWK's reliability services is available from info@wwk.com.

WWK to Release Detailed Report on 450mm Fab Economics

Although recent forecasts for 450mm IC wafer manufacturing by IC Knowledge [3] and SEMATECH[4] express optimism for the economics of 450mm wafers, detailed studies by WWK cast shadows on those forecasts. Others question 450mm as well:

- Hynix: "has no intention to build any 450mm fabs."[5]
- Micron: "the math … doesn't justify the enormous 450mm investment."[6]
- AMAT: "The 30% ISMI expectation [in processing costs] is a wishful thinking kind of statement, with no foundation."[7]

A summary of WWK's detailed forecasts of the financial impacts of 450mm manufacturing as compared to 300mm IC wafer manufacturing will be released 17 December 2007. The complete Factory Commander® analysis report can be purchased from WWK. For further information, contact info@wwk.com.



Relative Wafer Sizes from 2" to 450mm

---

[3] Scotten W. Jones, "A Simulation Study of the Cost and Economics of 450mm Wafers," *Semiconductor International*, 8/1/2005, downloaded 11/16/2007 from www.semiconductor.net
[4] Scott Kramer, "Transitioning to 300mmPrim and 450mm," *Semiconductor International*, 7/19/2007. downloaded 11/21/1007 from www.semiconductor.net
[5] Jin Seog Choi, quoted in "Hynix, Micro Execs Doubt Need for 450mm Wafers," Semiconductor.net, 11/12/2007, downloaded 11/21/2007 from www.semiconductor.net
[6] Steve Appleton, quoted in "Hynix, Micro Execs Doubt Need for 450mm Wafers," Semiconductor.net, 11/12/2007, downloaded 11/21/2007 from www.semiconductor.net
[7] Iddo Hadar, quoted in "ISMI Readies 450mm Test Bed, Wafer Bank," Semiconductor.net, 10/25/2007, downloaded 11/21/2007 from www.semiconductor.net

2009 iNEMI Roadmap Schedule

2007

October 12	Roadmap PEG kick-off with PEG/TWG/TC (at SMTAI; Orlando, FL)
November 14	Roadmap kick-off in Europe (at Productronica; Munich, Germany)

2008

January 11	Organizing teleconference with TWG Chairs (offer TWG meeting rooms at TWG kick-off)
February 20-21	PEG workshop/TWG kick-off (hosted by HP in Santa Clara, CA)
	Product sector tables completed – PEG chapter drafts written
	Cross-cut issues are initially addressed
April 3	TC/PEG face-to-face chapter review meeting at APEX, Las Vegas, NV
May 14	Open roadmap presentation in Herndon, VA
May 15	TC/TWG/PEG cross-cut meeting, Herndon, VA
June 12	European Roadmap Workshop at IMAPS UK MicroTech 2008, Windsor England
June TBD	Asian Roadmap Workshop in China
July 1	TWG drafts due for TC review
August 6-7	TC face-to-face review with TWG Chairs at Agilent (Liberty Lake, Washington)
September 21	**Final roadmap chapters due**
September 24	iNEMI Council of Members review of key issues, IPC Midwest, Schaumburg
November 20	"Go to press"
December 5	Ship to members

2009

1Q09	Make copies available to industry
2Q09	Industry presentation at APEX

If you would like to be involved with the 2009 iNEMI Roadmap team, or be added to the mailing list of this monthly newsletter, please contact Chuck Richardson at Chuck.Richardson@inemi.org.

Modeling Fab Utilities with Factory Explorer®

According the Mehmet Turkel, formerly of CH2M Hill's Industrial Design & Construction (IDC), "It appears that remodel-retrofit market [continues] to pickup steam. Potential clients with projects are clearly focused on the bottom line. Whether they have an internal, employee watchdog, or they hire an outside watchdog, design decisions are likely to be questioned many times over before being adopted in some form."

Historically, construction of utilities accounts for nearly 36% of construction cost on average. The major utility subsystems are shown in Figure 1.

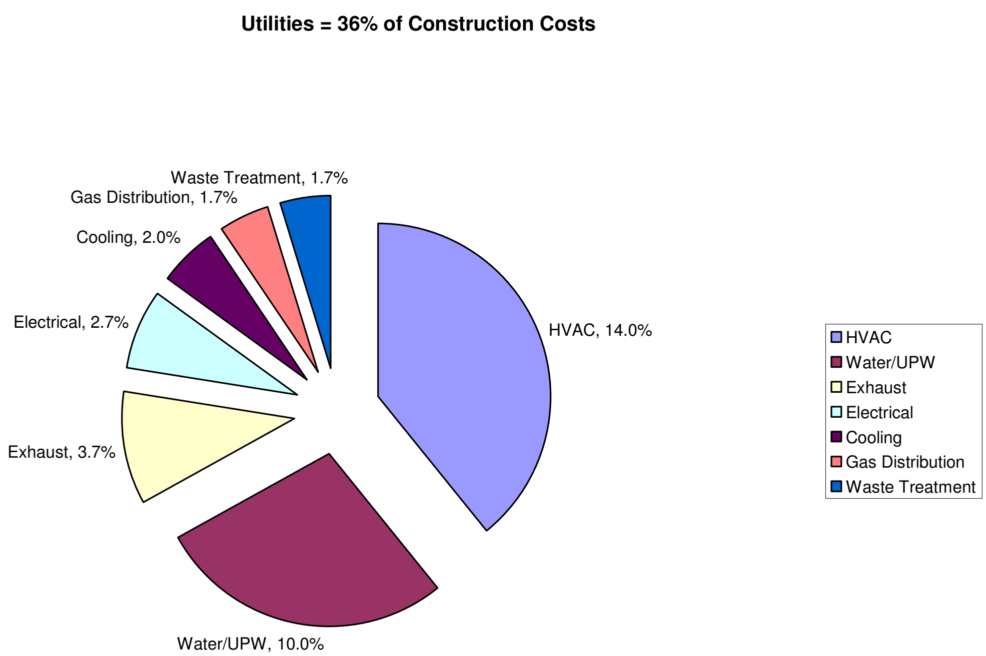


Figure 1: Utility Construction Breakout

The traditional method of determining utilities load for a fab is to sum the requirements from the equipment specifications and apply some type of a loading diversity factor to estimate fab utility requirements. However, equipment specifications represent maximum demand conditions, typically including some safety factor added by the equipment supplier. The combination of safety factors and the difference between maximum demand and typical demand help to insure that utility capacity requirements are greater than what is actually needed. This error has normally been ignored for new fabs, because that over sized capacity provides reserve for future growth.

However, the case is different for modifications to existing fabs, such as capacity expansions, new technology retrofits, or new process capabilities. Here much more accurate estimates of utility requirements are needed. The common method of summing specification requirements can require utility expansions that may not be needed.

If utility requirements are available by tool group, then Wright Williams & Kelly's (WWK) Factory Explorer simulation software (FX) can simulate fab utility demands under realistic conditions – before a modification and after. FX simulation can improve the accuracy of utility requirement estimates and provide customers with a competitive advantage.

For example, the peak electrical demand for a plasma etcher occurs during chamber pump-down after loading a new batch of wafers. This condition occurs for less than 10% of productive time. A typical fab may have more than 20 plasma etchers. It is highly unlikely that all plasma etchers would simultaneously initiate chamber pump-down. Yet electrical supply may have been sized for 20 simultaneous pump-downs, plus a safety factor. Cooling load has likewise been oversized to handle the heat dissipated by 20 tools at maximum electrical consumption.

An FX simulation using a wafer inter-arrival rate and dynamic utility loading conditions will estimate a distribution of electrical demand probabilities. The 99th percentile of this distribution should give a more accurate estimate of electrical requirements than present methods. The 99th percentile should also give a better estimate of cooling requirements. In a retrofit, these more accurate estimates would allow the customer to better plan the number of tools that could be addressed by the existing utilities. In a new design, a WWK FX simulation could "right size" the utilities for lean manufacturing.

While fine-tuning utility requirements through FX modeling will have some reduction in construction cost, the bigger impact will be on operating costs. Figure 2 assumes a fab building and utility construction cost of $225,198,000 and an annual depreciation of $9,008,000. This chart compares annual water, electrical, and waste treatment operating costs to the annual utility depreciation costs[8]. For simplicity, all electrical operating costs have been lumped into the electrical utility subsystem. Also included in electrical costs are the electrical demand charges, based on size of electrical supply. These do not change if actual consumption is lowered.

In this example, the annual utility operating cost of $20,566,000 is more than 6 times the annual $3,213,000 utility depreciation cost. Simply reducing the electrical demand charges by better electricity requirement estimates could make a significant financial impact.

[8] TWO COOL® analysis of 30,000 wafers per month fab.

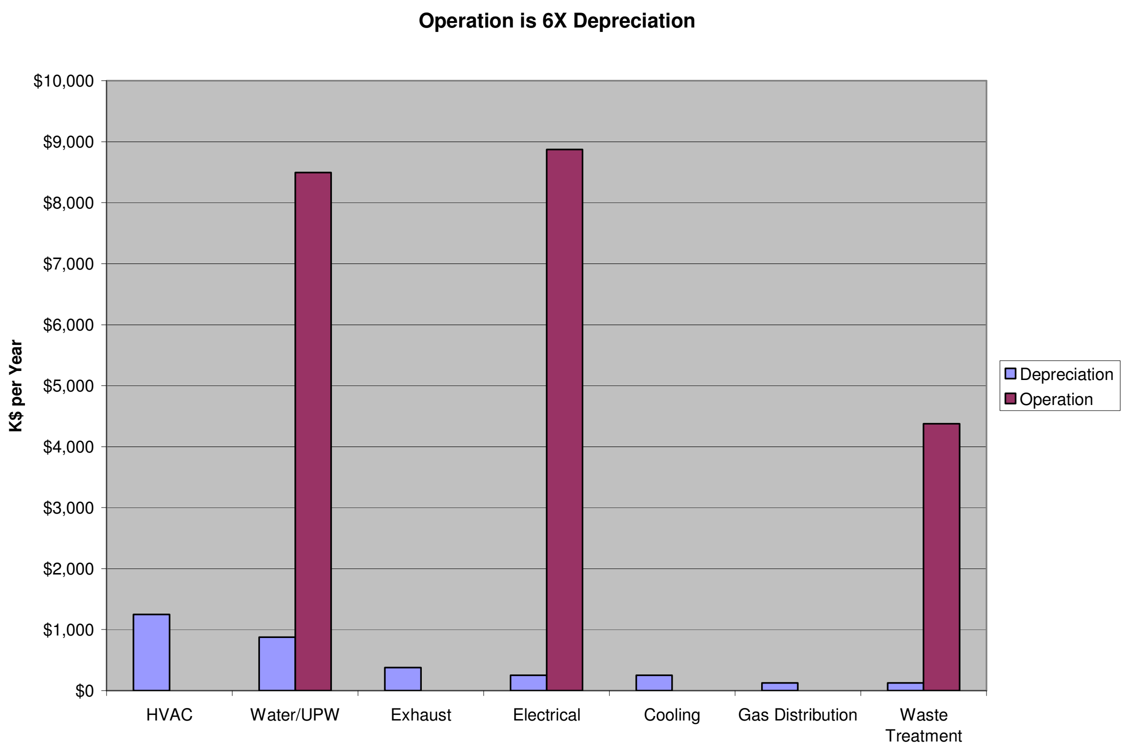


Figure 2: Utility Operating and Deprecation Costs