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Inside

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

[Continued on Page 3]

Editorial Board

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Calendar of Events

September 2009

30 **Solar/PV Manufacturing Market Outlook**
College of Nanoscale Science
Albany, NY

30 **SEMICON Taiwan**
Taipei World Trade Center
Taipei, Taiwan

October 2009

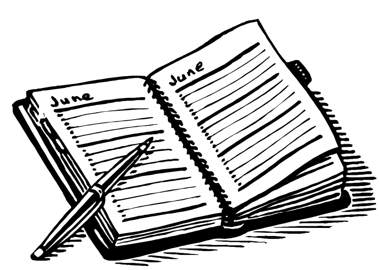
6-8 **SEMICON Europa**
Messe Dresden
Dresden, Germany

7-9 **PV Taiwan**
Taipei World Trade Center
Taipei, Taiwan

26 **Understanding & Using Cost of Ownership & Factory Productivity**
Solar Power International
Anaheim Convention Center
Anaheim, CA

Solar Power Web Site

27-29 **Solar Power International**
Anaheim Convention Center
Anaheim, CA



Chapter 9
Secondary Reliability Improvement Process

In the last chapter, we described a generic Reliability Improvement Process (RIP) and its associated four major steps. In this chapter, we will study a secondary RIP that exists at steps 2 through 4 of the generic RIP (see figure 8.1, ACM Winter 2009). As shown in figure 9.1, the secondary RIP is an iterative process and consists of the following five basic activity steps.

1. Assessment
2. Comparison
3. Decision
4. Root cause identification
5. Corrective actions

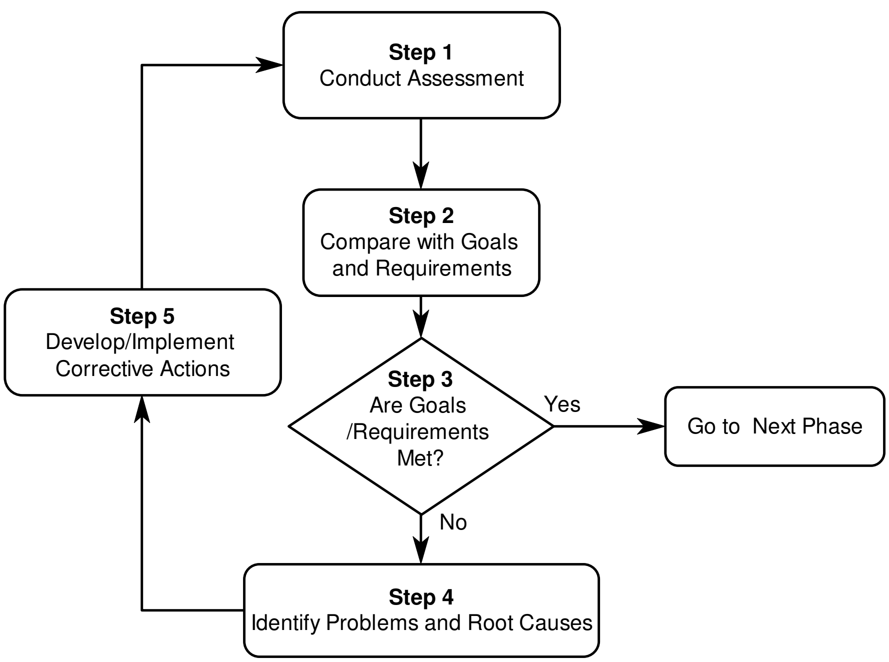


Figure 9.1 Secondary Reliability Improvement Process

Let's look at each step in detail.

9.1 Assessment

At this step, the reliability level of the current equipment design configuration is assessed. Depending upon the life cycle phase the product is in, this could be either calculated value or observed value (either during in-house tests or in the field).

EXAMPLES:

- When equipment is in the design and development phase, reliability modeling or other analytical techniques are used to assess its reliability level.
- When equipment is in the prototype phase, in-house test data are used to assess the reliability level.
    - When equipment is in the pilot production or production phases, in-house test and/or field performance data are used to assess the reliability level.

9.2 Comparison

At this step, results of the assessment stage are compared to established reliability goals and requirements.

9.3 Decision

This is a decision-making step, in which a decision is made to move either to the next product life cycle phase or to continue improving reliability level. If the goals and requirements are not met, identify the problems and root causes, as described in the next stage and initiate reliability improvement activities. If goals and requirements are met or exceeded, approval is given to move to the next phase of the life cycle, where the RIP is again applied.

9.4 Root Cause Identification

If the decision is to continue improving the reliability, then identify root causes for the shortfalls in reliability level. Reliability modeling, test data from prototype tests, or actual equipment field data are used to identify causes of the shortfalls.

If the equipment is in the design and development phase, use results of reliability modeling or other analytical techniques to identify major contributors in the system failure rate. Work with these components to develop corrective actions.

If equipment is in the prototype, pilot production, or production phases, use results of the in-house test and/or field performance data and identify problems with high occurrence rate. Work with these problems to develop corrective actions.

Once the root causes are identified, they are assigned to proper persons to develop corrective actions described in the next section.

9.5 Corrective Actions

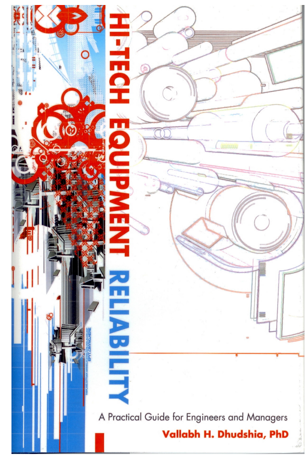
At this step, corrective actions are developed to eliminate or reduce the effect of the identified root causes. Corrective actions could include changes in parts/components design, material and/or supplier, manufacturing process, operating procedure and environment, maintenance procedure, training, or software. The type of corrective action depends upon the life-cycle phase the product is in.

The process then returns to the conduct assessment step and the other steps are repeated until the goals and requirements are met.

The above steps are described in greater detail in reference 1.

REFERENCES

1. SEMATECH, *Guidelines for Equipment Reliability*, Technology Transfer #92031014A-GEN (Austin, TX: SEMATECH, Inc., May 1992).



WWK Software Versions

TWO COOL® v3.1.5
(v3.2 in development including Japanese language support)

PRO COOL® for Process Sequences v1.2

PRO COOL® for Wafer Sort & Final Test v1.2

Factory Commander® v3.2.5

Factory Explorer® v2.10.1

Overall Equipment Efficiency (OEE): A Tutorial

David W. Jimenez, Daren L. Dance
Wright Williams & Kelly, Inc.

Abstract

Overall Equipment Efficiency (OEE) is the most recent high-level equipment performance metric. It started as overall equipment effectiveness, developed in Japan as an equipment metric on the effectiveness of a manufacturing technique called Total Productive Maintenance (TPM). The American Institute of Total Productive Maintenance (AITPM) is currently the major sponsor of using the OEE metric in the United States. With increased use in the United States, it was renamed overall equipment efficiency.

The following tutorial discusses the history of OEE and how it fits into other equipment metrics. Additionally, we discuss the definition of OEE, its applications, misuses, and its relationship to cost of ownership (COO).

History[2]

OEE was created in Japan during the late 1960's by Nippondenso, a major manufacturer of automobile parts, as part of the development of Total Productive Maintenance (TPM). TPM focuses on eliminating 16 major losses that affect production efficiency.

- seven major losses affecting equipment effectiveness
- planned equipment idle time for preventive maintenance, overhaul, and operator meetings
- five major losses affecting manpower efficiency, and
- three major losses of material and energy utilization

Originally OEE was a metric used to determine how much loss was related to the equipment and where these losses occurred. OEE measured the seven major losses of equipment and categorized them into four areas; Availability, Utilization, Throughput Rate, and Yield.

Semiconductor companies in the United States became very interested in OEE during the mid 1990's, so a task force was formed and SEMI[3] E79 was created to establish a common metric and define OEE as a true equipment efficiency measurement that included all aspects of equipment performance. There were two areas of the original OEE metric that the semiconductor industry felt needed to be addressed to make OEE more useful.

1. To include planned equipment idle time in the OEE calculation. Including planned idle time in the calculation identified opportunities to increase equipment utilization by streamlining activities and reducing ineffective scheduled downtime.

[2] Based on information provided by V.A. Ames, Equipment Manager, SVTC Technologies, Austin, TX.
[3] Semiconductor Equipment & Materials International, San Jose, CA, www.semi.org.

2. To base all measurements on time. Basing all measurements on time affected the yield measurement that had previously been calculated as good parts produced/total parts produced. As a review of SEMI E79 will show, using time to calculate yield provides the opportunity to identify a greater loss of efficiency.

Many variations of OEE are used around world across all types of industries. We have found that the SEMI E79 standard is all inclusive and adaptable for use in many applications for today's semiconductor industry.

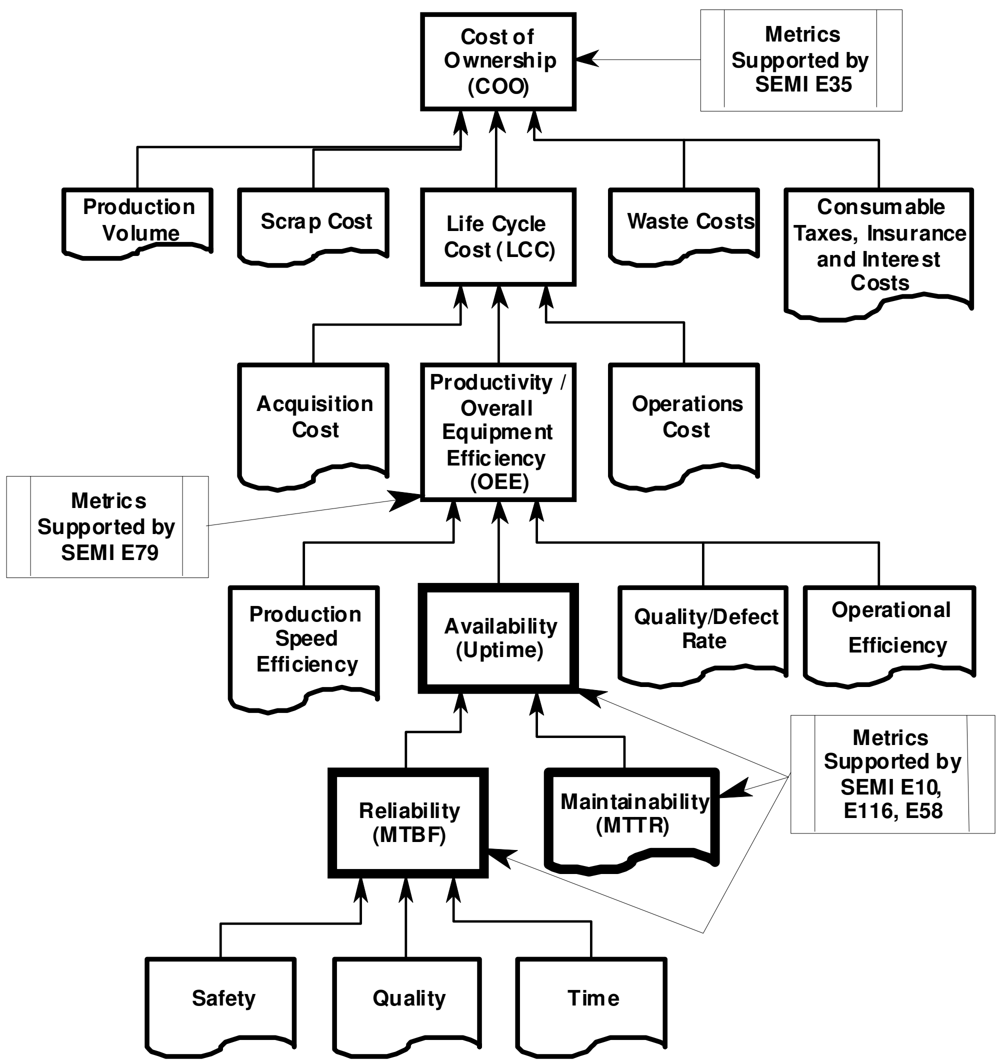


Figure 1: Hierarchy of Equipment Performance Metrics[4]

[4] Dr. Vallabh Dhudshia, Hi-Tech Equipment Reliability: A Practical Guide for Engineers and Managers, iUniverse, 2008.

Relationship to other metrics

There are many equipment performance metrics at different levels. They may appear disjointed; however, that is not true. They all fit nicely into a hierarchal tree.

Figure 1 depicts the hierarchy tree of the equipment performance metrics. As shown in the figure, when a time dimension is added to quality and safety, it becomes reliability. Reliability and maintainability jointly make up availability. When production speed efficiency and production defect rate are combined with availability, it becomes productivity (OEE). Acquisition and operational costs make up Life Cycle Cost (LCC). When scrap, waste, consumables, tax, and insurance costs are added to LCC and the total is normalized by the production volume, it becomes COO.

Definition: E79

Productivity is defined as good unit production rate in relation to the available capacity of the equipment. One of the most popular productivity metrics is OEE. It is based on reliability (MTBF), maintainability (MTTR), throughput, utilization, and yield. All these factors are grouped into the following four submetrics of OEE.

1. Availability (joint measure of reliability and maintainability)
2. Operational efficiency
3. Throughput rate efficiency
4. Yield/quality rate

OEE is defined by SEMI E79 as "the fraction of total time that equipment is producing effective units at theoretical efficiency rates." From a high level perspective, OEE can be reduced to the following equation:

$$OEE = \text{Theoretical Production Time for Effective Units} / \text{Total Time}$$

Or

$$OEE = \text{Availability Efficiency} \times \text{Performance Efficiency} \times \text{Quality Efficiency}$$

Availability Efficiency

Availability Efficiency is defined as "the fraction of equipment uptime that the equipment is in a condition to perform its intended function." Availability Efficiency is represented in the following equation:

$$\text{Availability Efficiency} = \text{Equipment Uptime} / \text{Total Time}$$

Performance Efficiency

Performance Efficiency is defined as "the fraction of equipment uptime that the equipment is processing actual units at theoretically efficient rates." Performance Efficiency is represented in the following equation:

ISSN 1094-9739

Performance Efficiency = Operational Efficiency x Rate Efficiency

Or

Performance Efficiency = (Production Time / Equipment Uptime) x (Theoretical Production Time for Actual Units / Production Time)

Quality Efficiency

Quality Efficiency is defined as "the theoretical production time for effective units divided by the theoretical production time for actual units." Quality Efficiency is represented in the following equation:

Performance Efficiency = Theoretical Production Time for Effective Units / Theoretical Production Time for Actual Units

As we see above, it requires many parameters to calculate OEE. If the accuracy requirement is not a critical factor, use the following formula to calculate an approximate OEE value:

OEE = Number of Good Units Output in a Specified Period of Time / (Theoretical Throughput Rate x Time Period)

OEE Example

The following facts are known. In a period of one week, a piece of equipment:

1. Was not scheduled for production for 48 hours
2. Was down for scheduled and unscheduled maintenance for 2 and 4 hours, respectively
3. Had production rate of 80 PPH versus its theoretical PPH of 100
4. Yielded 15 rejects out of the total 9,120 production units

Using the above equations, we can calculate OEE as:

$$OEE = ((168 - 48 - 2 - 4) / 168) \times (80/100) \times ((9120 - 15) / 9120) = 51.4\%$$

Applications

OEE is frequently used to improve the usage or productivity of an existing equipment set. Better understanding of OEE of the constraining equipment (the bottleneck equipment) can result in capacity improvements that increase the potential usage of every other equipment set in the factory. For example, a production schedule that improves lithography OEE by reducing time lost due to mask or reticle changes can increase the capacity of the entire fab. Lithography is frequently the factory constraint. Improved lithography OEE will result in better usage of non-lithographic equipment sets by reducing standby or idle time. Thus, an improvement at the constraint equipment improves the OEE of all the manufacturing equipment.

In less automated operations such as assembly or test, staffing may be more of a constraint than equipment availability. By understanding the OEE category of "waiting for operators," an improved staffing schedule can also improve the OEE of all the manufacturing equipment.

Limitations and misuses

Not all of the equipment used in manufacturing should have high OEE. Diagnostic equipment can best impact production when it is readily available for use if a manufacturing problem should occur. Wafer test, for example, can be improved by periodic inspection of the characteristics of the probe mark on the wafer. If several operators are waiting for an available inspection microscope, then the higher OEE of the microscope comes at a result of lower OEE for the test systems.

A non-manufacturing example is fire-fighting equipment. High utilization – thus, high OEE – of a fire truck means that it may not be available in an emergency. Low utilization of the fire truck – thus, low OEE – means that a fire truck is much more likely to be standing by when needed, thus, preventing a costly catastrophe.

Finally, OEE analysis without cost analysis may result in high OEE at the expense of cost of ownership increases. This is more fully explored in the next section.

Use with COO

Since OEE is a subset of COO and lacks any activity based cost related input or output, it is highly recommended COO be considered when applying OEE to non-bottleneck or non-near-bottleneck equipment. Since COO is limited by definition to looking at the cost impacts of individual process steps, OEE improvements in bottleneck tools are best measured in terms of cost or revenue impacts by factory level modeling tools such as WWK's Factory Commander® software.

Non-Bottleneck Example

An equipment engineer is looking at improving the OEE of a particular tool. One avenue for improvement is to provide on-site maintenance labor and repair parts. The cost difference is $20,000 per shift but reduces response time from 4 hours to 0.25 hours and mean time to repair (MTTR) from 8 hours to 4 hours.

As can be seen from Figure 2, OEE has been improved by almost 3%. However, the question remains, at what cost? By combining OEE with COO, the equipment engineer is in a better position to determine if this change is appropriate.

The COO results from Figure 3 show that the 3% improvement in OEE comes at an increase of 5% in cost. However, this process step can now deliver an additional 200 wafers per week. If the factory can make use of that additional capacity, directly or through cost avoidance, then this may be a good investment in OEE improvement.

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	Off Site	On Site
Overall Equipment Efficiency	**73.43**	**76.28 Percent**
Availability Efficiency	**84.18**	**87.44 Percent**
Engineering Usage	0.00	0.00 Hours/Week
Standby	0.00	0.00 Hours/Week
Hours Available/System (Productive Time)	141.42	146.91 Hours/Week
Down Time	26.58	21.09 Hours/Week
Scheduled Maintenance	14.00	14.00 Hours/Week
Unscheduled Maintenance	8.89	3.39 Hours/Week
Test	3.50	3.50 Hours/Week
Assist	0.20	0.20 Hours/Week
Non-Scheduled Time	0.00	0.00 Hours/Week
Equipment Uptime	141.42	146.91 Hours/Week
Total Time	168.00	168.00 Hours/Week
Performance Efficiency	**87.50**	**87.50 Percent**
Throughput At Capacity/System	35.00	35.00 Layers/Hour
Theoretical Throughput	40.00	40.00 Layers/Hour
Operational Efficiency	100.00	100.00 Percent
Rate Efficiency	87.50	87.50 Percent
Quality Efficiency	**99.69**	**99.69 Percent**
Equipment Yield	99.99	99.99 Percent
Defect Limited Yield	99.95	99.95 Percent
Parametric Limited Yield	99.75	99.75 Percent
Alpha Error Factor	100.00	100.00 Percent
Beta Error Factor	100.00	100.00 Percent
Redo Rate	0.00	0.00 Percent

Figure 2: OEE for On-Site and Off-Site Maintenance Strategies

	Off Site	On Site
Cost Per System	1,000,000	1,000,000 Dollars
Number Of Systems Required	1	1 Systems
Total Depreciable Costs	1,015,000	1,015,000 Dollars
Equipment Utilization Capability	86.26	89.53 Percent
Production Utilization Capability	84.18	87.44 Percent
Composite Yield	99.69	99.69 Percent
Good Wafer Equivalents Out Per Week	4,934.21	5,125.82 G.W.E.'s
Good Wafer Equivalent Cost		
With Scrap	5.12	5.36 Dollars
Without Scrap	2.06	2.30 Dollars
Average Monthly Cost		
With Scrap	109,669	119,337 Dollars
Without Scrap	44,112	51,233 Dollars
Process Scrap Allocation		
Equipment Yield	1.64	1.64 Percent
Defect Limited Yield	16.35	16.35 Percent
Parametric Limited Yield	82.01	82.01 Percent
Equipment Costs (Over Life of Equipment)	1,305,363	1,305,363 Dollars
Per Good Wafer Equivalent	0.72	0.70 Dollars
Per Good cm2 Out	0.0029	0.0028 Dollars
Recurring Costs (Over Life of Equipment)	7,906,857	8,718,906 Dollars
Per Good Wafer Equivalent	4.39	4.66 Dollars
Per Good cm2 Out	0.0175	0.0185 Dollars
Total Costs (Over Life of Equipment)	9,212,219	10,024,268 Dollars
Per Good Wafer Equivalent (COO)	**5.12**	**5.36 Dollars**
Per Good Wafer Equivalent Supported	5.12	5.36 Dollars
Per Good cm2 Out	0.0204	0.0213 Dollars
Per Productive Minute	2.97	3.12 Dollars

Figure 3: COO for On-Site and Off-Site Maintenance Strategies

Conclusions

While OEE is the most recent high-level equipment performance metric in semiconductor manufacturing, it has over 40 years of use as part of the Japanese culture of TPM. OEE is built on the framework of other SEMI standards dealing with equipment reliability, availability, and maintainability (E-10). Within the hierarchy of equipment metrics, OEE is a mid-level metric that is best applied to bottleneck and near-bottleneck equipment sets. By focusing OEE on these tool groups, the incremental productivity gained can be leveraged across the entire factory. By combining the power of OEE with COO, the end user can not only understand where productivity gains may be made but also at what cost.

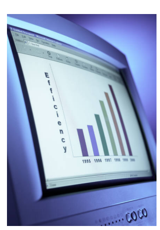
Acknowledgements

The authors would like to express their gratitude to Dr. Vallabh Dhudshia, Mr. Jim Irwin, and Mr. V.A. Ames for their contributions to this article. All are recognized as leaders in the areas of equipment reliability and productivity and can be reached directly or through Wright Williams & Kelly, Inc.

Biographies

Mr. Jimenez is President and co-Founder of Wright Williams & Kelly, Inc. (WWK), the largest privately held operational cost management software and consulting services company. He has approximately 30 years of industrial experience including management positions with Mobil Oil and NV Philips. He holds a B.Sc. in Chemical Engineering from the University of California, Berkeley and an MBA in Finance. He was also responsible for the design of the semiconductor industry's de facto standard in cost of ownership and overall equipment efficiency, TWO COOL®, and holds a patent for his work on PRO COOL® for Wafer Sort & Final Test. He is a recipient of the Texas Instruments Supplier Excellence Award for his contributions to their cost reduction efforts. For over 15 years, he has been a facilitator in the SEMI sponsored workshop "Understanding and Using Cost of Ownership." He is also the author of numerous articles in the fields of productivity and cost management.

Mr. Dance is Vice President of Technology for WWK. Prior to joining WWK, he was a senior member of technical staff in Operational Modeling at SEMATECH where he managed Cost of Ownership development projects and examined energy strategies and their cost impacts on manufacturing. He has extensively modeled semiconductor manufacturing operations to understand true long-term manufacturing costs and capabilities. Mr. Dance has held the positions of co-chair of the Semiconductor Equipment and Materials International (SEMI) Metrics Committee and the yield model and defect budget team co-leader for the Semiconductor Industry Association (SIA) International Technical Roadmap for Semiconductors (ITRS). He was a staff engineer with American Microsystems (AMI), Pocatello, ID, where he was involved in yield modeling, manufacturing capacity simulation, and cost modeling.



WWK Hosts Cost of Ownership Seminar at Solar Power International

Largest Solar Power Tradeshow in the U.S.

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 & Using Cost of Ownership and Factory Productivity," during Solar Power International 2009. "Understanding & Using Cost of Ownership and Factory Productivity" will be held at the Anaheim Convention Center on Monday, October 26 from 9am to 5pm. This seminar covers major aspects of Cost of Ownership (COO), Overall Equipment Efficiency (OEE), and Factory Productivity from fundamentals to hands-on applications and has been designed specifically for the needs of the photovoltaics (PV) industry.

Registration for this seminar can be done directly on the Solar Power web site at http://www.solarpowerinternational.com or by following the link on the WWK home page at http://www.wwk.com. There is limited seating available for this seminar, so please contact Solar Power International 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.

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.

Wright Williams & Kelly, Inc. Offers Software Maintenance Amnesty

Offers No Penalty Sign Ups to Help Clients Prepare for Upturn

Wright Williams & Kelly, Inc. (WWK), the global leader in cost and productivity management software and consulting services, announced today an amnesty program for companies that dropped their maintenance coverage during the latest extended high tech downturn. The amnesty program will run through the end of October 2009.

Companies interested in returning to a maintenance agreement should contact their local sales and support office or contact WWK's headquarters at 925-399-6246. Clients returning to maintenance will be provided with free updates to the latest software versions as well as on-going support. The contracts will begin as of the day of the order and will not be back dated to the previous expiration, providing clients a significant savings.

"WWK recognizes that software maintenance agreements are the first to be cut in a downturn," stated David Jimenez, WWK's President. "However, this last downturn was significantly deeper and longer than previous cycles. As a result, our clients were forced to make many very difficult decisions. We don't believe that they should be punished for making cost cutting decisions in that type of environment. As a result, we are offering our clients the ability to get back on board without any penalties, so they will be prepared to take advantage of the upturn in the economy."

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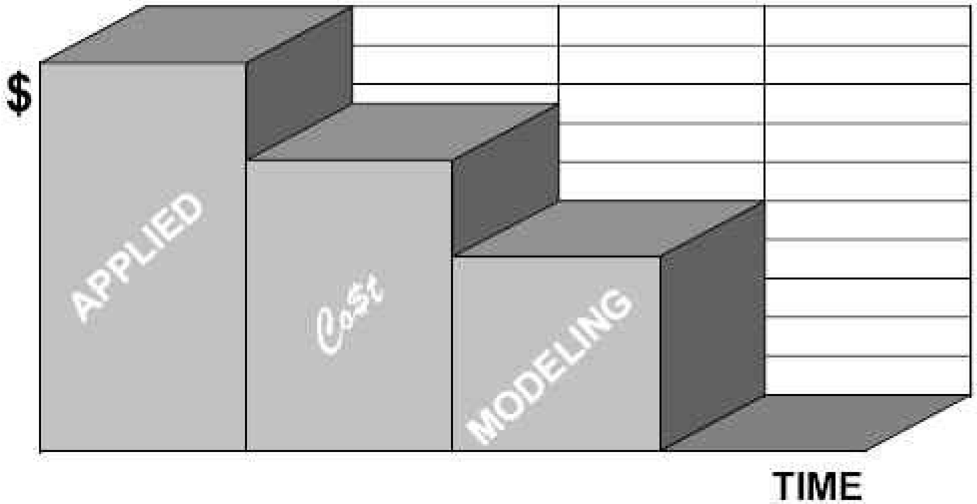
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