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

[Continued on Page 3]

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Calendar of Events

September 2008

29 **ISA Solar PV Conclave 2008**
SCOPE Convention Center
New Delhi, India

October 2008

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

7-9 **SEMICON Europa**
Trade Fair Centre
Stuttgart, Germany

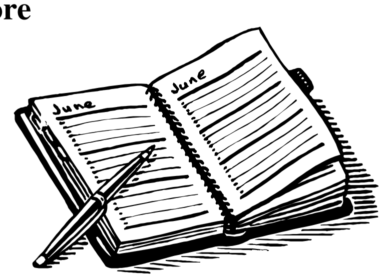
29-31 **FPD International 2008**
Pacifico Yokohama
Yokohama, Japan

November 2008

3-4 **Equipment RAMP for Semiconductor Manufacturing Workshop**
Berjaya Times Square Hotel
Kuala Lumpur, Malaysia

3-5 **SEMI North American Metrics Standards**
SEMI Headquarters
San Jose, CA

6-7 **Equipment RAMP for Semiconductor Manufacturing Workshop**
Parkroyal on Kitchener Road
Singapore



Reliability in the High-Level Equipment Performance Metrics

In real life, we always face the question, "What should be the proper level of reliability?" A simple answer would be "the higher, the better." However, the answer cannot be that simple. To answer this question, our industry has developed high-level equipment performance metrics for which reliability is a key element. The proper level of the reliability is the one that yields the optimal value of the high-level metric being considered.

These high-level equipment performance metrics are becoming increasingly important to compete in the global market because they satisfy the customer's reliability requirements in an optimum manner.

We already defined one high-level metric, availability, in chapter 5, section 5.5. We also studied the effect of reliability on availability. In this chapter we will describe the following three high-level equipment performance metrics:

1. Productivity/Overall Equipment Efficiency (OEE)
2. Life Cycle Cost (LCC)
3. Cost of Ownership (COO)

6.1 Productivity/Overall Equipment Efficiency

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 Overall Equipment Efficiency (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

The four submetrics and OEE are mathematically related as follows (equation 6.1):

$$OEE, \% = availability \ x \ operational \ efficiency \ x \ throughput \ rate \ efficiency \ x \ quality \ rate \ x \ 100$$

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 effectiveness metric to measure 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 gradually increased use in the United States, it became overall equipment efficiency.

Now let us look at each OEE submetric in more detail.

Availability

We have already defined availability in chapter 5. There are many variations in the availability calculation, most of which stem from their definitions of uptime. In this book, we will stick to the following simple definition, but acknowledge that more precise ways are available (equation 6.2).

$$Availability = \frac{equipment\ uptime}{total\ time}$$

WHERE:

Equipment uptime includes actual production time, other usages of the equipment (such as engineering runs), and standby time.

Operational Efficiency
The operational efficiency is the fraction of the equipment uptime that the equipment is actually manufacturing the products. It is given by (equation 6.3):

$$Operational\ efficiency = \frac{production\ time}{equipment\ uptime}$$

Throughput Rate Efficiency
The throughput rate efficiency is the fraction of production time the equipment is manufacturing products at the theoretical throughput rate (equation 6.4).

$$Throughput\ rate\ efficiency = \frac{actual\ production\ rate}{theoretical\ production\ rate}$$

Quality Rate
The quality rate is a measure of output quality and it is given by (equation 6.5):

$$Quality\ rate = \frac{total\ parts\ produced - rejects}{total\ parts\ produced}$$

A Simple Way to Calculate OEE
As we see above, it requires many parameters to calculate the OEE. If the accuracy requirement is not a critical factor, use the following formula to calculate an approximate OEE value estimate quickly (equation 6.6).

$$OEE,\% = \frac{number\ of\ good\ units\ output\ in\ a\ specific\ time\ period\ x\ 100}{theoretical\ throughput\ rate\ x\ time\ period}$$

An Example of OEE Calculations
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 equations (6.1) through (6.5), we have

$$OEE,\% = \frac{168-48-2-4}{168}\ x\ \frac{80}{100}\ x\ \frac{9120-15}{9120}\ x100$$

$$OEE,\% = 0.678\ x\ 0.8\ x\ 0.998\ x\ 100 = 54.1\%$$

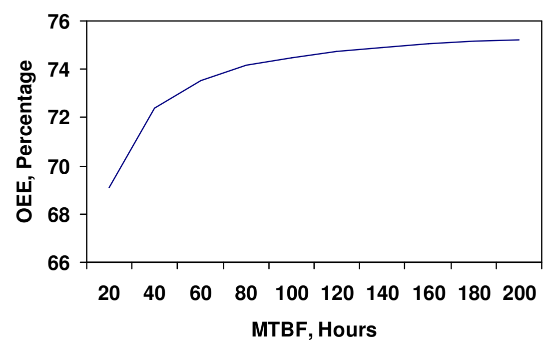


Figure 6.1 A Typical Relationship between Reliability (MTBF) and OEE

Note that OEE does not directly include any cost-related factor in its calculations.

Standardization of Productivity Metrics Calculations
Just like SEMI Specification SEMI E10 for RAM metrics, SEMI has a specification for calculating equipment productivity (OEE) metrics for the semiconductor manufacturing equipment (SEMI E79). See reference 1.

6.2 Life Cycle Cost (LCC)

Life Cycle Cost (LCC) is the total cost of acquiring and operating equipment over its entire life span. LCC includes all supplier and customer costs incurred from the point at which the decision is made to acquire the equipment, through its operational life, to eventual disposal of the equipment.

LCC is an older metric than OEE and is based on the equipment's cost factors. It has been in use for many years to determine the optimal level of reliability that generates minimum LCC, as shown in figure 6.2. It has also been used to perform trade-offs between acquisition and operational costs.

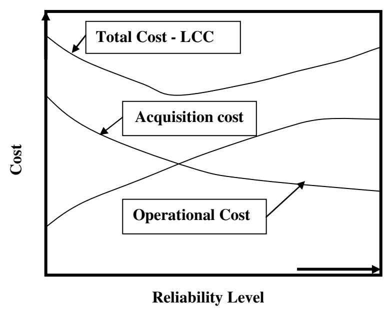


Figure 6.2 A Typical Reliability Level versus Life Cycle Cost

Two main elements of the LCC are: (1) acquisition cost and (2) operational cost. Supplier costs plus the supplier's gross profit is referred to as acquisition costs and are passed to the customer in the purchase price of the equipment costs. These include:

- Research and development
- Basic engineering and design
- Testing and evaluation
- Manufacturing, parts, materials, tools, and labor
- Quality and reliability assurance
- Supplier-provided packaging, shipping, and installation
- Supplier-provided training and support
- Marketing and sales
- Warranty costs
- Supplier profit

Costs incurred by the customer are referred to as operational costs and include:

- Supply process management
- Customer installation and training
- Repair and maintenance (unscheduled and scheduled) costs
- Spare parts and their inventory
- Operational personnel
- Training
- Facility and utilities
- Materials
- Cost of scrapping the equipment less the scrap value

Since all elements of LCC do not occur in the same year, we need to consider one more factor, named "time value of money," in the LCC calculations. This factor converts all costs incurred after the first year to an equivalent present value (worth) in the first year. The present value discount factors are found in any interest rate table. Table 6.1 contains an example of typical LCC calculations.

Cost Item	Year in Which Cost Incurred			
	2007	2008	2009	2010
Acquisition Cost	500,000			
Installation Cost	50,000			
Operational Cost	35,000	50,000	55,000	70,000
Repair and Maintenance Cost	30,000	33,000	36,000	50,000
Removal Cost				10,000
Scrap Value				(5,000)
Subtotals	615,000	83,000	91,000	125,000
Present Worth Factor*	1.0000	0.9259	0.8573	0.7938
Present Worth in 2007 Dollars	615,000	76,852	78,018	99,229
	Total LCC in 2007 Dollars = 869,100			

* Assuming 8% rate of interest (inflation rate)

Table 6.1 A Typical Life Cycle Cost Calculation

A variety of LCC models are available. Reference 2 contains the most commonly used LCC models.

6.3 Cost of Ownership (COO)

LCC is one of the most widely used high-level metrics, but it has the following shortcomings. It does not include:

- Effect of the production volume
- Product scrap loss because of poor quality output

- Consumable cost
- Waste disposal cost
- Taxes, insurance, and interest expenses

To overcome the above, SEMATECH developed a Cost of Ownership (COO) model, as described in reference 3. COO is the full cost of embedding, operating, and decommissioning in a factory environment the equipment needed to accommodate the required volume of product units. It is based on true cost of an equipment ownership per good unit produced in a given time period, usually a calendar year. The COO metric is expressed as cost per good unit for one pass through the equipment.

The COO depends upon the equipment acquisition cost, operating cost, the production throughput rate, equipment reliability, throughput yield, equipment utilization, and yield loss. The basic COO is given by the following equation (equation 6.7).

$$COO\ per\ unit = \frac{FC + OC + YLC}{NGU}$$

WHERE:
FC = Fixed costs (amortized for the period under consideration)
OC = Operating costs
YLC = Yield loss costs
NGU = Number of good units produced during the time period

Let's comprehend the above factors in a little more detail.

<u>Fixed costs</u>
The fixed costs are typically determined from a variety of items such as: purchase price, taxes and duties, transportation costs, installation cost, start-up cost, and training cost. The allocation to the time period under consideration is strictly a function of the allowable depreciation schedule and the length of the time period.

<u>Operating costs</u>
The operating costs for a piece of equipment are consumables, maintenance, parts, waste disposal, facility operations (including utilities), and equipment operators.

<u>Yield loss costs</u>
The yield loss costs are those associated with lost production units that are directly attributable to the specific equipment operation.

<u>Number of good units produced</u>
The number of good units produced depends upon:

- Throughput rate: Throughput rate is the production rate of the equipment, usually expressed in parts per hour.
- Throughput yield: Throughput yield is the fraction of good units produced.
- Utilization: Utilization is the fraction of the total time that a tool is available for production.

For more elaborate COO calculations, refer to reference 3.

COO Input Data:	
Equipment Acquisition Cost = $ 1,000,000	Equipment Life = 5 Years
Throughput Rate = 20 Units/Hour	Throughput Yield = 0.98
Operation Cost = $ 800,000/Year in 2007	Part Cost = $ 50,000/Year in 2007
Labor Rate = $ 50/Hour in 2007	PM Time = 20 Hours per Month
MTBF = 200 Hours	MTTR = 2 Hours
Utilization = 75%	Inflation Rate = 4% per Year

Cost Factors	**COO Calculation for Year**				
	2007	**2008**	**2009**	**2010**	**2011**
Depreciation, $	200,000	200,000	200,000	200,000	200,000
Operational cost, $	800,000	832,000	865,280	899,891	935,887
Repair & Main. Cost, $	66,260	68,910	71,667	74,533	77,515
Yield Loss, $	250,000	260,000	270,400	281,216	292,465
Total Cost, $	**1,316,260**	**1,360,911**	**1,407,347**	**1,455,641**	**1,505,867**
Good Unit Produced	128,772	128,772	128,772	128,772	128,772
COO per Unit, $	**10.22**	**10.57**	**10.93**	**11.30**	**11.69**

Table 6.2 A typical COO Calculation

Many functional areas use the COO value as one of their critical factors, including competitive analysis, benchmarking analysis, materials cost-impact analysis, equipment selection, and project prioritization. In addition, COO analysis is an excellent marketing tool for sales personnel.

Standardization of Cost of Ownership Calculations

Just like SEMI specification SEMI E10 for RAM metrics, SEMI has a guideline for COO metrics calculations for the semiconductor manufacturing equipment (SEMI E35). See reference 4.

6.4 Hierarchy of Equipment Performance Metrics

As we show in chapter 3 and in this chapter, there are many equipment performance metrics at different levels. They appear disjointed. However, that is not true. They all fit nicely into a hierarchy tree.

Figure 6.3 depicts the hierarchy tree of the equipment performance metrics. As shown in the figure, when we add time dimension 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 (overall equipment efficiency). Acquisition and operational cost make up Life Cycle Cost (LCC). When scrap, waste, consumables, tax, and insurance cost are added to LCC and the total is normalized by the production volume, it becomes Cost of Ownership (COO).

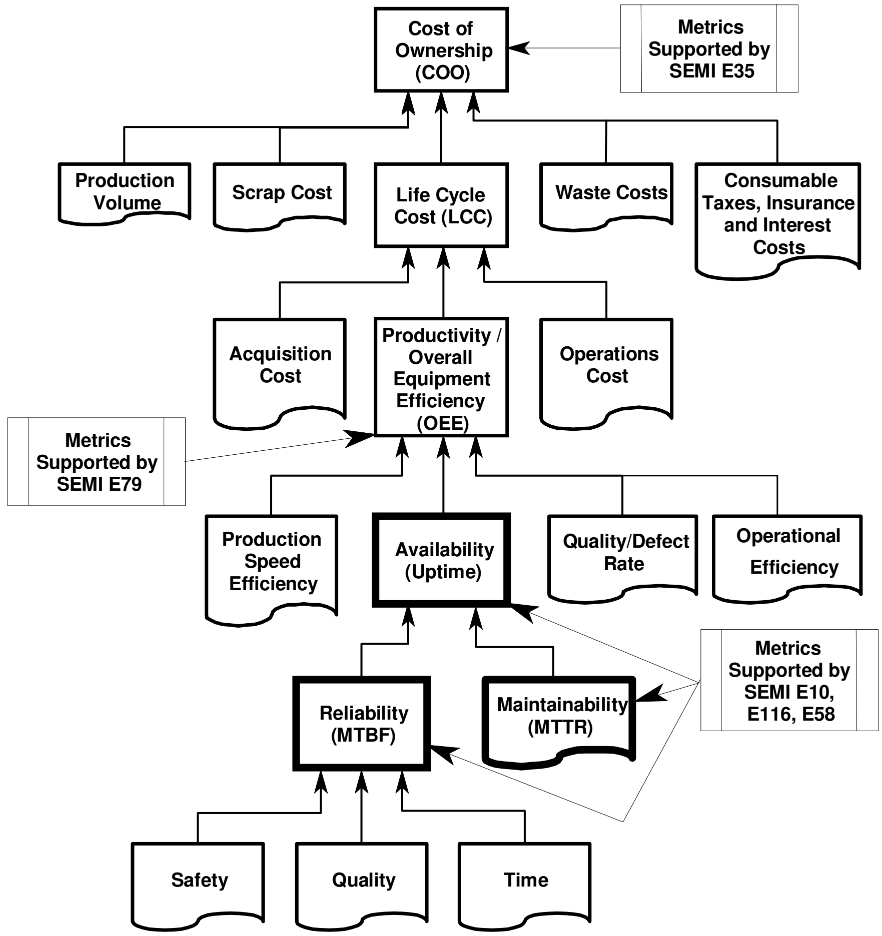


Figure 6.3 Hierarchy of Equipment Performance Metrics

REFERENCES

1. *SEMI Specification SEMI E79-0304, Specification for Definition and Measurement of Equipment Productivity (San Jose, CA: SEMI, 1999, 2004).*
2. *MIL-HDBK-338, Electronic Reliability Design Handbook, 15 October 1984.*
3. *SEMATECH, Cost of Ownership Model, Technology Transfer Document # 91020473B-GEN (Austin, TX: SEMATECH, Inc., 1992).*
4. *SEMI Guideline SEMI E35-0307, Guide to Calculate Cost of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment (San Jose, CA: SEMI, 1995, 2007).*

Equipment RAMP
(Reliability, Availability, Maintainability and Productivity)
For Semiconductor Manufacturing

3 (Mon) & 4 (Tue) November 2008
Berjaya Times Square Hotel
Kuala Lumpur, Malaysia

6 (Thu) & 7 (Fri) November 2008
Parkroyal on Kitchener Road
Singapore

Meet Dr. Vallabh H. Dhudshia in person and learn everything from definition and identification to measuring, testing, and improving your equipment and products for maximum reliability and productivity.

In this 2-day workshop, Dr. Vallabh H. Dhudshia provides a comprehensive and concise reference manual for all engineers and engineering managers who know that maximum reliability and productivity of equipment and product is a mission-critical factor to the success of any organization.

In a factual and thorough manner, Dr. Dhudshia describes different reliability disciplines and measurement techniques, as well as reliability and productivity improvement processes and testing methods. In addition, he clearly defines the phases of the equipment life cycle associated with reliability and productivity and the three primary growth mechanisms for each stage of the equipment's maturation.

Understanding that reliability and productivity is at the very core of an organization's customer service capability, Dr. Dhudshia makes a compelling case for pursuing a corporate-wide program of reliability and productivity improvement education and implementation. He not only proposes the basic structure of such reliability and productivity programs but also delivers recommendations for structuring reliability and productivity teams as part of an overall quality program as well as discusses ways to target, assess, and correct reliability and productivity problems.

Attendance of this workshop is essential for anyone who desires a thorough understanding of product and equipment reliability and productivity.

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IC Production on 450-mm Wafers: Still Never

Recent Survey of Semiconductor Industry Insiders Reconfirms Future Battle Lines

Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced the results of its annual survey on equipment and process timing in the semiconductor industry. The details behind this survey are currently being distributed to survey respondents and will also be included in an upcoming article in Fabtech Issue #38. Some of the compiled results include:

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

- 193-nm high index immersion lithography
- Wafer-level reliability testing
- Imprint lithography

However, survey respondents did not expect to see the following technologies in production until 2014 or beyond:

- EUV lithography
- 450-mm wafers
- Directed self assembly nanoresists

Respondents also expect productivity advances from ISMI's 300-mm Prime project to be implemented on an ongoing basis.

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 2015 or beyond but we were surprised that over half of the respondents indicated that 450-mm wafers would never happen in production manufacturing. This was an increase in negative sentiment over the 2007 results. Thus, we expect that fabs can plan on a significant useful life from their current investments in 300-mm manufacturing equipment."

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 Consulting Affiliate Interviewed on CNBC Asia

As you may remember, in February 2008 Wright Williams & Kelly, Inc. and The Fairview Group, Inc. co-sponsored an important and informative briefing on the state of the Chinese semiconductor industry. The briefing was conducted by Dr. Danny Lam based on his years of access to key players in the Chinese government and industrial complex.

Dr. Lam's follow up to that briefing was an early August 2008 report entitled "Special Situation Report: Is a Global Post-Olympics Crash Coming?" That special report has caught the attention of major Asian financial organizations, including CNBC Asia. Dr. Lam was recently interviewed on CNBC as part of their study of post-Olympics China; WWK is proud to be able to provide access to that interview on our web site at http://www.wwk.com under the left side link "Resources."

If you invest in Asia or in companies that do business in Asia, "Special Situation Report: Is a Global Post-Olympics Crash Coming?" is a must read. The report is priced at US$5,000 and comes with a private 20 minute debriefing with Dr. Lam.

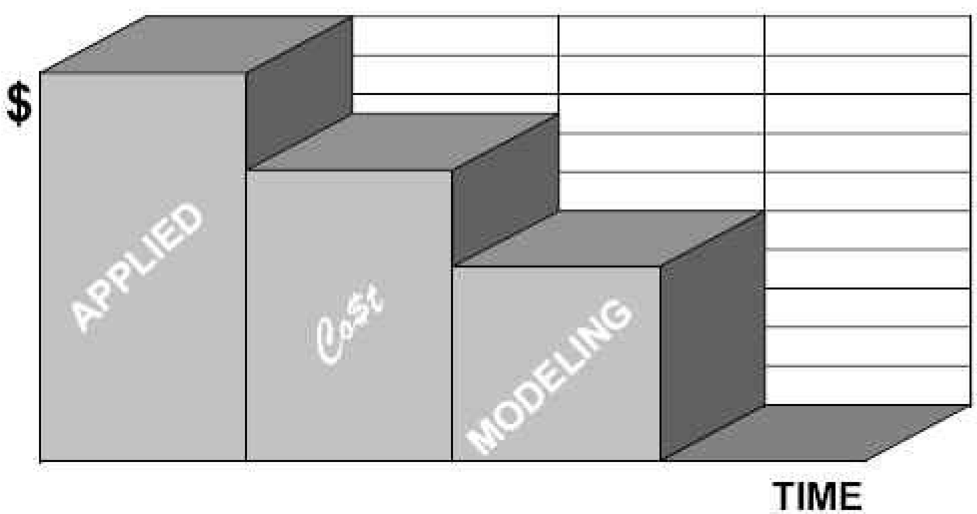
Dr. Danny Lam is an energy and semiconductor analyst and editorial writer at The Fairview Group, Inc., publisher of the Global Communications and Computing Report. His work has appeared in Semiconductor International, Handbook of Technology Management, Semiconductor Fabtech, EE Times, Wall Street Journal, Business Week, etc.

During his 25 year career in the industry, semiconductor lithography line width went from 6-7 microns down to 45 nanometers; wafers grew from 4" to 12"; and the industry boomed and busted to ultimately plateau at its present growth rate of about 9% per annum. He believes he will live to see the end of Moore's law. Along the way, Dr. Lam has visited most of the major fab sites in the US and Asia and evaluated semiconductor industry development programs from Hsinchu, Taiwan to Wuhan, China.

He received his PhD from Carleton University in 1992 with a dissertation on the development of Taiwan's microelectronics industry and has been a fellow at the Belfer Center for Science and International Affairs, Kennedy School of Government, and Harvard University.

Late Breaking News: WWK Racks Up Twin Solar Installations

Just before this issue of Applied Co$t Modeling hit the press, WWK received purchase orders from two photovoltaic (PV) companies. One is a global supplier of turnkey factories and the other is a PV manufacturer. Please keep your eyes out for the formal press releases scheduled for September 24, 2008 and early October 2008.



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