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Inside

Summer 2011

Cost of Ownership and Overall Equipment Efficiency: A Photovoltaics Perspective

With this edition of Applied Cost Modeling, we are publishing the first installment in a series on the application of cost of ownership (COO) and overall equipment efficiency (OEE) to photovoltaic cell manufacturing.

Introduction

It is not surprising that the photovoltaics industry has adopted many of the same metrics developed for the semiconductor industry. With suppliers serving both markets, Semiconductor Equipment and Materials International (SEMI) organized the PV Group to, among other things, look at the portability of standards between these two industries. This paper will examine the application of two such standards, Guide to Calculate Cost of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment (SEMI E35[1]) and Specification for Definition and Measurement of Equipment Productivity (SEMI E79[2]). This latter standard defines the OEE metric. Recent work at the National Renewable Energy Laboratory (NREL) regarding cost reduction also references SEMI E35. The application of these standards is examined using a case study comparing an in-line doping furnace and a $POCl_3$ batch furnace.

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Calendar of Events

October 2011

11-13 SEMICON Europa
Messe Dresden
Dresden, Germany

17-21 Solar Power International
Dallas Convention Center
Dallas, TX

24-27 SEMI North America Standards Meetings
SEMI Headquarters and Intel
San Jose and Santa Clara, CA

November 2011

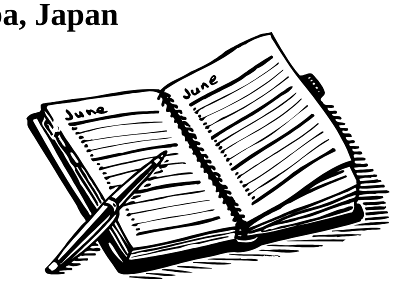
9-11 Solarcon India
Hyderabad Convention Centre
Hyderabad, India

14-15 Concentrated Photovoltaic Summit
Convention Plaza Hotel
San Jose, CA

December 2011

5-7 PV Japan
Makuhari Messe
Ciba, Japan

7-9 SEMICON Japan
Makuhari Messe
Ciba, Japan



History

In the mid-1980's companies became more concerned with understanding the concept of COO. COO is the analysis of all costs associated with the acquisition, use, and maintenance of a good or service. This analysis takes more than price into consideration. It may also consider product quality, failure costs, administrative costs, and maintenance, among other factors.

What has been discovered is that low price does not always mean the lowest total cost or satisfactory performance. COO is a tool that allows a company to determine the most cost effective product or service. Activity Based Costing and Activity Based Cost Management also support the concept that cost allocation should be linked to the activity that causes the cost to be incurred.

Recent trends have increased the interest in COO:

1. Quality Emphasis: The tighter the specification, the higher the quality, and the higher the supplier price. How tight a specification should be to see lower reject rates, improved quality, and higher customer satisfaction is a question answered by COO analysis.

2. Supply Base Rationalization: Reduce the number of suppliers but use suppliers that have high quality standards, low cost, and responsive service. COO analyses help to determine which suppliers to keep.

3. Increased Global Competition: Japanese businesses have a thorough understanding of how to manage total costs on a purchasing and total product basis. This is a part of their accounting practice. Companies competing on a global basis must have access to cost data to determine their competitive position in the market.

COO models in the semiconductor industry began at Intel Corporation, where, in the mid-1980's, a concentrated analysis began of the total cost of acquiring, maintaining, and operating purchased equipment. Intel's objective was explicit: develop a purchasing methodology that establishes a sound, quantitative, business-like basis for equipment acquisition. The COO concept first came to SEMATECH when one of Intel's employees was assigned to the Strategic/Competitive Analysis area.

The original SEMATECH COO models developed were not very user-friendly. However, they improved over time and received wide acceptance. During the early 1990's, SEMATECH decided not to introduce any changes to their model so users could become familiar and comfortable with the software. They determined that this would not occur if the software was always in a state of flux[3].

Once COO was an accepted part of the semiconductor industry, SEMATECH decided to move forward in providing enhanced versions of COO software. To that end, SEMATECH contracted Wright Williams & Kelly, Inc. in 1994 to provide on-going worldwide support and training for COO as well as enhanced software products. These enhanced software models have been commercially available on a worldwide basis since 1995 and were updated to include other manufacturing areas, including photovoltaics, in 2000.

OEE[4] 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 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. To base all measurements on time. Basing all measurements on time affected the yield measurement, which 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 the world across all types of industries. We have found that the SEMI E79 standard is all inclusive and adaptable for use in many applications including those in the photovoltaics industry.

Basic COO Algorithm

Estimating equipment COO is neither complex nor difficult. With a few significant details, users can determine the life-cycle cost of owning a photovoltaic process equipment. The basic COO algorithm is described by:

$$CU = \frac{CF + CV + CY}{L \times TPT \times YC \times U}$$

Where:

C_U	=	Cost per good unit (wafer,cell, module, etc.)
C_F	=	Fixed cost
C_V	=	Variable cost
C_Y	=	Cost due to yield loss
L	=	Process life
TPT	=	Throughput
Y_C	=	Composite yield
U	=	Utilization

Fixed costs include purchase, installation, and facility costs that are normally amortized over the life of the equipment. Variable costs such as material, labor, repair, utility, and overhead expenses are costs incurred during equipment operation. While correctly a subset of variable costs, yield loss cost is a measure of the value of units lost through breakage and misprocessing and is broken out separately to demonstrate the importance of yield to both the numerator and denominator. Process life is the length of time the process is in operation. Throughput is based on the time to meet a process requirement such as depositing a nominal film thickness. Composite yield is the operational yield of the process and includes breakage and misprocessing. Utilization is the ratio of production time compared to total available time.

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 sub-metrics 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 = Theoretical Production Time for Effective Units / Total Time

Or

OEE = Availability Efficiency x Performance Efficiency x 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:

Availability Efficiency = Equipment Uptime / 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:

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)

Relationship Between 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 cost are added to LCC and the total is normalized by the production volume, it becomes COO.

References

1. E35, Guide to Calculate Cost of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment, www.semi.org.
2. E79, Specification for Definition and Measurement of Equipment Productivity, www.semi.org.
3. Richard L. LaFrance and Stephen B. Westrate, "Cost of Ownership: The Supplier's View," Solid State Technology, July 1993, p 33-37.
4. Based on information provided by V.A. Ames, Project Manager, ISMI, Albany, NY.
5. Dr. Vallabh Dhudshia, Hi-Tech Equipment Reliability: A Practical Guide for Engineers and Managers, iUniverse, 2008.

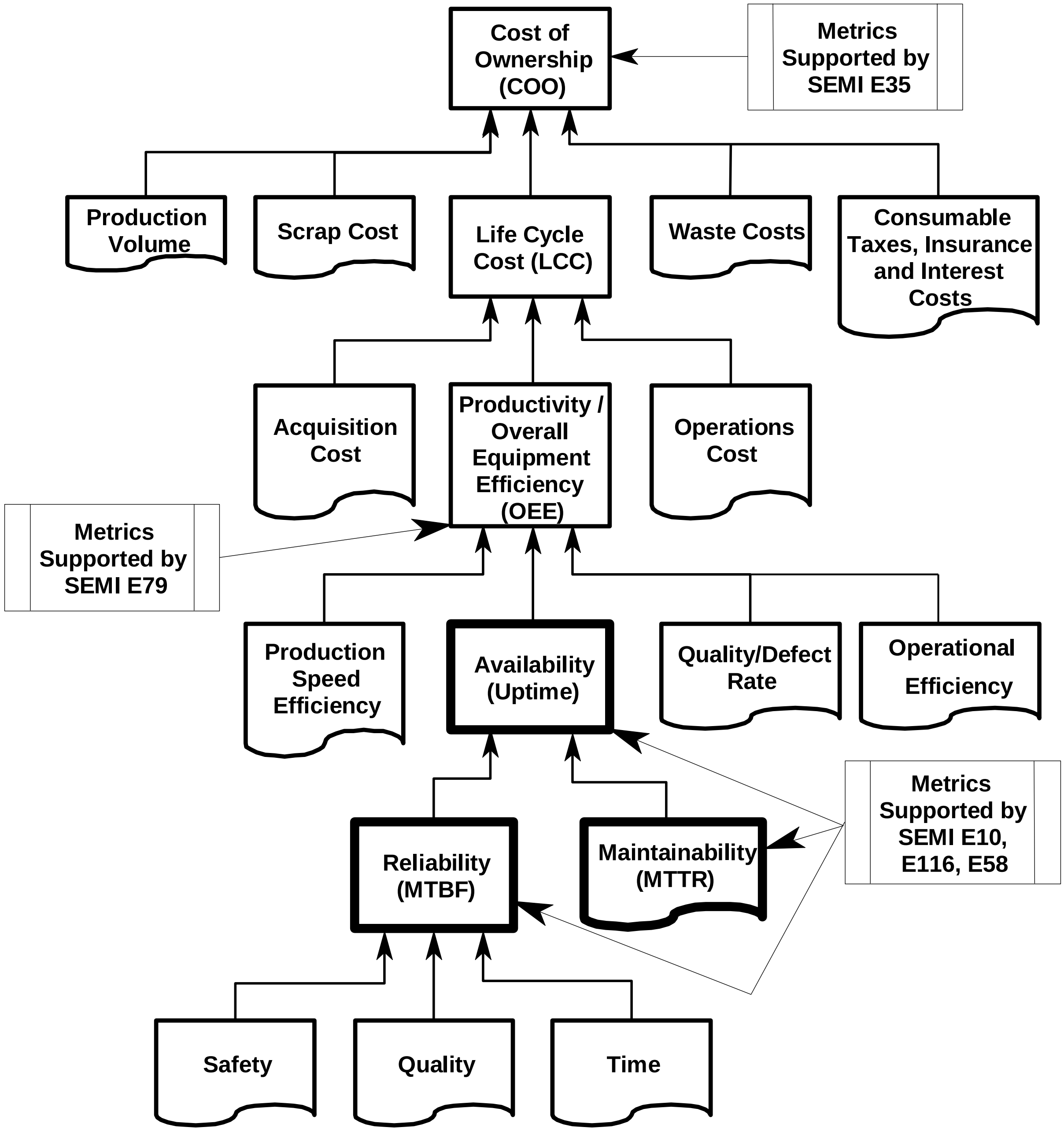


Figure 1: Hierarchy of Equipment Performance Metrics[5]

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Wright Williams & Kelly Names Global Link as Sales Agent

Strategic Restructuring in Japan Strengthens Sales and Service

Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today a strategic transition of its sales and support in Japan to Global Link Corporation. This transition represents the continuation of WWK's strategic vision to provide increased sales and service support in close proximity to all of its customers, world-wide.

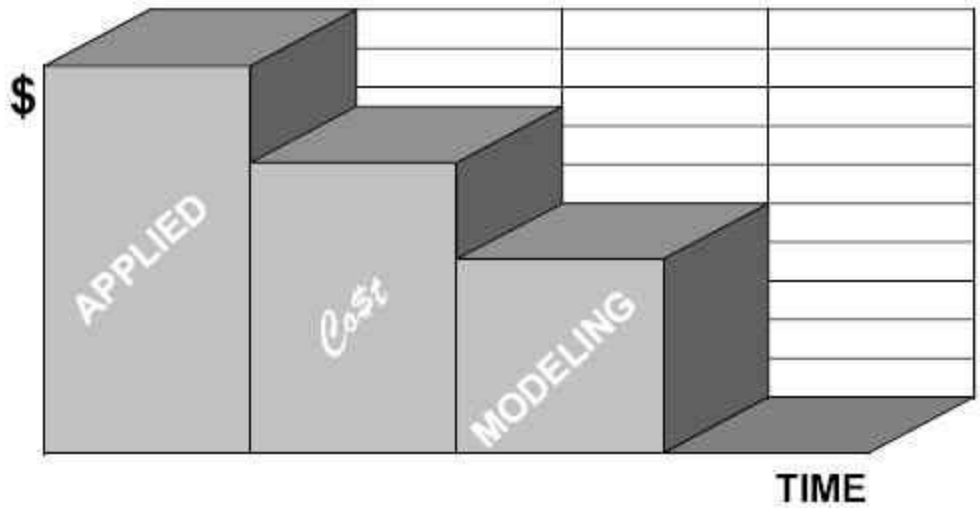
"Global Link Corporation was selected to support our established and growing installed base in Japan based on their ability to successfully meet the needs of their clients," states David W. Jimenez, WWK's President. "They combine a comprehensive understanding of the region's manufacturing climate with an extensive background in sales and support. We look forward to working with them to support our existing installed base and expanding the application of our software products and services."

"We are pleased to begin representing WWK and its product line. Their products and services fit nicely with our offerings in other software and hardware areas," says Mike Iwakata, President of Global Link Corporation. "We see a large demand for software tools and consulting services designed to help optimize manufacturing costs and productivity. WWK will help keep our clients at the forefront of cost competitive operations."

Global Link Corporation (GLC) is a privately held company offering components for photovoltaic manufacturing, high-tech manufacturing equipment, lithium ion battery systems, manufacturing optimization software, and consulting services for these product areas. GLC also has a strong relationship with information technology (IT) systems integrators enabling turnkey solutions.

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), 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 recording heads, magnetic media, flat panel displays (FPD), solid state lighting/light emitting diodes (SSL/LED), 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.



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