FabTime Cycle Time Management Newsletter

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Information

Mission: To discuss issues relating to proactive wafer fab cycle time management.

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Welcome

Welcome to Volume 2, Issue 4 of the FabTime Cycle Time Management Newsletter. Back in Volume 1, Issue 6 (September 27th, 2000) we had an issue on performance measurement in which we defined various performance measures for wafer fabs. In this current issue, we're focusing exclusively on the performance measure OEE (Overall Equipment Effectiveness). OEE is something that we're asked about a lot. Most people are familiar with it on some level, but may not know how to calculate it, or where to find resources on OEE. We thought that there would be benefit in collecting this information in one place. If we've missed anything, please let us know.

We also have a conference announcement and a description from Scott Mason of his new Razorback Electronics Manufacturing Lab at Arkansas.

Thanks for reading! -- Jennifer

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In-Depth Guide to OEE Resources

Background

Most of our readers are familiar with the general concept of Overall Equipment Efficiency (OEE). OEE is a tool-level measure reflecting how much good product the tool produced relative to some theoretical amount that it could have produced. Typical OEE values in a wafer fab are less than 50%. Given the high cost of equipment, there is a clear incentive to make OEEs as high as possible. OEE is the measurement that's used in TPM (Total Productive Maintenance), a methodology for improving the entire manufacturing process.

In this article, we review the formulas for calculating OEE (both the full formula and a short-cut version), as well as some of the reasons for low OEE in wafer fabs. We also include a series of links to OEE resources on the Internet (including primary resources from SEMI and SEMATECH), as well as some additional published OEE references.

Theoretical Method of Calculating OEE

This discussion was derived from information in the SEMATECH OEE Guidebook.

OEE = Availability x Performance Efficiency x Quality Rate

Availability is equipment uptime expressed as a percentage of total time. That is:

Availability = (Equipment Uptime) / (Total Time)

where

Equipment Uptime = (Productive Time) + (Standby Time) + (Engineering Time).

[Note: See SEMI E-10 for term definitions.]

Equivalently:

Availability = (Total Time - NonScheduled Time - Unscheduled Downtime - Scheduled Downtime) / (Total Time).

Performance Efficiency is a factor consisting of rate efficiency (ideal process time over actual process time) and operational efficiency (time spent processing vs. time available for processing). That is:

Performance Efficiency = Rate Efficiency x Operational Efficiency

where

Rate Efficiency = (Ideal Process Time) / (Actual Process Time)

and

Operational Efficiency = Total Productive State Time / Equipment Operational Uptime.

In the above, Total Productive State Time is time that the tool is busy processing regular production wafers, engineering production wafers, or rework wafers. Equipment Operational Uptime is the sum of productive, engineering, and standby states.

Rate of quality is simply good wafers processed divided by total wafers processed. That is:

Rate of Quality = ((Total Wafer Processed - Rejects)/(Total Wafers Processed)) x 100.

Summary:

OEE is the product of six types of performance losses, grouped into three categories. The first two are the Availability losses due to unscheduled equipment downtime (1) and scheduled equipment downtime (2). The next two losses are Performance Efficiency losses due to idling and minor stoppages (3) and reduced speed of equipment (4). The last two losses are Rate of Quality losses due to rework (5) and wafer or yield losses (6).

Example:

Availability: Suppose that in a given week, a tool is down 30 hours for planned maintenance, 4 hours for a planned holiday factory shutdown, 7 hours for an unplanned downtime, and 3 hours for an unplanned power outage (the tool is in California). Then the availability is (168 - (30 + 4 + 7 + 3))/168 = (168 - 44)/168 = 124/168 = .738

Performance Efficiency:

Rate Efficiency: Suppose that the ideal average process time for the tool is 4 minutes per wafer, but that we observe that when the tool is processing, it takes 5 minutes to process each wafer. The Rate Efficiency = Ideal Process Time / Actual Process Time = 4/5 = 0.8.

Operational Efficiency: Suppose that over a given week, the tool spends 55 hours processing production wafers, 3 hours processing rework wafers, and 15 hours processing engineering production wafers. The tool also spends 7 hours in an engineering state, and 44 hours in a standby state. Then the operational efficiency = (55 + 3 + 15) / (55 + 3 + 15 + 7 + 44) = 73 / 124 = .5887. Note that the denominator is 124, which is the same as the numerator in the availability equation (total time minus downtime).

Performance Efficiency = 0.8 x 0.5887 = 0.471

Rate of Quality: Suppose that during the time described, a total of 876 wafers were processed, of which 36 were rework wafers, and 52 wafers were scrapped. Then the Rate of Quality = (Total Wafers Processed - Rejects)/(Total) = (876 - 36 - 52)/876 = 788/876 = 0.900

OEE = A x PE x QR = 0.738 x 0.471 x .900 = .313

Short-Cut Method of Calculating OEE

OEE = (Good Wafers) / (Maximum Theoretical Throughput)

Where Max Theoretical Throughput = (Total Time) / (Ideal Proc Time per wafer)

To see this, remember:

OEE = A x PE x QR = [(Equip Uptime) / (TotalTime)] * [(Ideal Proc Time)/(Actual Proc Time)] * [(Productive Time) / (Equip Uptime)] * [(Good wafers)/(Total Wafers)]

Canceling (Equip Uptime) in the numerator and denominator, we have:

OEE = [1 / (Total Time)] * [(Ideal Proc Time)/(Actual Proc Time)] * [(Productive Time) / 1] * [(Good wafers)/(Total Wafers)]

Substituting in (Max Theoretical Throughput) for (Total Time) / (Ideal Proc Time):

OEE = [1 / (Max Theo Throughput)] * [1 / (Actual Proc Time)] * [(Productive Time) / 1] * [(Good wafers)/(Total Wafers)]

In the denominator, we have (Actual Proc Time) * (Total Wafers), which is equal to (Productive Time) (assuming Actual Proc Time is an average across Total Wafers), so we can cancel several more terms, leaving:

OEE = [1 / (Max Theo Throughput)] * [1 / 1] * [1 / 1] * [(Good Wafers) / 1]

So we simply have:

OEE = (Good Wafers) / (Max Theo Throughput)

Example:

From our case above, (Good Wafers) = 788.

And (Max Theo Throughput) = (Total Time) / (Ideal Proc Time) = 168 hours per week / (4 mins / wafer) = 168 hours / (4/60 hours/wafer) = 168 * 15 wafers / hour = 2520 hours per week.

So OEE = 788 / 2520 = 0.313 (same as above!)

One reason to calculate OEE from its constituent terms (the longer method), is that this shortcut calculation does not tie the efficiency loss to any one underlying factor. Using the constituent terms, you can quantify the various sources of efficiency loss, and tackle them individually.

Reasons for Low Observed OEE

There are many reasons for low observed OEE values. Unreliable equipment is most commonly blamed, but that only tells part of the story. Variability in lot arrivals is also a significant contributor, especially when it leads to bottleneck starvation. Running non-productive wafers (test and monitor wafers) can lead to major OEE reductions, as can setups, scrap, and rework. Operator unavailability is another contributor. Also, of course, due to varying granularity of the equipment groups, many tools just have extra capacity, and thus have an increased percentage of standby time (which reduces OEE). Some of these attributes are preventable (surely we want to get to a point of having no scrap, and no rework). Others are necessary consequences of business decisions, as when we plan extra idle time on non-bottlenecks to keep down cycle time, or when we plan to run a certain number of development wafers through as an investment in remaining on the cutting edge. But in most cases, working to improve OEE (especially the OEE of bottleneck tool groups) will drive towards improving the bottom line.

Links to Additional Information

■ SEMI E79 - http://www.semi.org/PUBS/SEMIPUBS.NSF/174288043ec0808d882565f6000b285b/a34b8f0e38c9e987882567450070d447!OpenDocument. This is the SEMI standard for equipment productivity, based on OEE, and is the primary source for the semiconductor industry's definition of OEE. There is a $50 charge to download this document for individual users. If your company is a SEMI member, you may be able to download it with no charge, or find it on your company's website. E79 was re-written in 2000. At that time, OEE was renamed to Overall Equipment Efficiency from the previous name, Overall Equipment Effectiveness. E79 relies on equipment status being recorded using the SEMI E10 standard for equipment states (available from http://www.semi.org/PUBS/SEMIPUBS.NSF/174288043ec0808d882565f6000b285b/2605676403344e08888256516007bdbf2!OpenDocument, also for a $50 fee).

- SEMATECH OEE Guidebook - http://www.sematech.org/public/docubase/summary/2745agen.htm. Written in 1995, this document (available for free download from SEMATECH), defines SEMATECH's approach towards OEE, and how to deploy OEE improvement projects.

- http://www.manufacturingit.net/Sections/management/Overall%20Equipment%20Effectiveness/OEEIntro.shtml This is a nice, brief, web-based introduction to OEE, taken from a book called "The Lean Toolbox." The site is maintained by a UK-based consulting firm called Cerulean Consulting (http://www.industrialconsulting.co.uk/).

- http://www.link2semiconductor.com/articles/danc1019_p.htm - This article describes, at a high level, the relationship between Cost of Ownership (COO) and OEE. The article was written by Daren Dance of Wright Williams & Kelly, a world-wide authority on COO.

- http://esrc.berkeley.edu/csm/csmab.html (CSM-41) - The Competitive Semiconductor Manufacturing Program has a report entitled: "Field Study of Overall Equipment Efficiency (O.E.E.) Measurement of 5X Steppers". You can purchase the report from the CSM website for $10 to $30 (depending on whether or not your company participated in the CSM studies). Another paper from the same website is CSM-45: "Proposed Revision to SEMI's Standard for Definition and Measurement of Equipment Productivity". This latter paper addresses some of the issues that we touched on in Volume 1, Number 6, concerning OEE for non-bottleneck tools that have planned idle time.

- http://www.tpmonline.com/. This site is a resource for people interested in TPM and other Lean Manufacturing techniques. It is available in English and Spanish.

Additional References

- J. Bonal, C. Ortega, L. Rios, S. Aparicio, M. Fernandez, M. Rosendo, A. Sanchez, and S. Malvar, "Overall Fab Efficiency," *Proceedings of the 1996 IEEE/SEMI Advanced Semiconductor Manufacturing Conference*, 49-52, 1996. This paper describes a factory-level metric based on OEE, Overall Fab Efficiency, developed by industrial engineers at Agere Systems.

- P. Jonsson and M. Lesshammar, "Evaluation and Improvement of Manufacturing Performance Measurement Systems - The Role of OEE," *International Journal of Operations and Production Management*, Vol. 19, No. 1, 55-78, 1999.

- J. Konopka, W. Trybula, "Overall Equipment Effectiveness (OEE) And Cost Measurement," *Proceedings of the Nineteenth IEEE/CPMT International Electronics Manufacturing Technology Symposium,* Austin, TX, 137-140, 1996.

- R. C. Leachman, "Closed-Loop Measurement of Equipment Efficiency and Equipment Capacity," *1995 IEEE/SEMI Advanced Semiconductor Manufacturing Conference*, 115-126. Also published in *IEEE Transactions on Semiconductor Manufacturing,* Vol. 10, No. 1, 84-97, 1997.

- OEE for Operators: Overall Equipment Effectiveness (Shopfloor Series), Productivity Press, 1999 (available from Amazon).

Conclusions

The power of OEE is that it provides a clearly defined metric by which equipment performance improvement projects can be measured. SEMI and SEMATECH have gone to great lengths to define OEE, and also the necessary supporting metrics like the SEMI E-10 equipment states. The nice thing about this is that it means that you can compare OEE values across factories, and even across companies, and get a true picture of your factory's performance. Another nice thing about OEE is that it drives you to do good things, like reduce setup and rework and scrap and starvations due to WIP or operator shortages. By focusing on the six types of losses highlighted by OEE, you can design a strong equipment improvement program, and monitor your progress through trends in the overall metric.

Community News/Announcements

ISSM Call for Papers:

International Symposium on Semiconductor Manufacturing (ISSM 2001) will be held on October 8-10, 2001 at the Fairmont Hotel in San Jose, California. ISSM is the premier event for learning, sharing and networking with our industry. This symposium has been held in Japan and in the U.S. in alternate years since 1992 and brings together people from all major semiconductor companies throughout the world.

The concept of a Symposium revolves around interaction amongst the participants. The event features workshops, interactive presentations, and general and breakout sessions with industry leaders. This year's workshops will focus on 300mm Manufacturing and Manufacturing Issues at the 70nm Node.

We invite you to share your professional experiences at the Tenth International Symposium on Semiconductor Manufacturing. Abstracts are due April 20th. Prospective authors must submit a two-page abstract, consisting of one page text and one page figures/tables. The abstract must be written in English, and formatted in Microsoft Word. Please e-mail the Abstract to issm@meetingsplus.com as an attachment, before Friday, April 20, 2001. Each abstract must be accompanied by complete contact information for the principal author. Authors will be notified of the acceptance of papers in June 2001. Selected final papers will be due August 10, 2001. Complete conference information and Call for Papers can be found at http://www.issm.com. For any questions, please email us at issm@meetingsplus.com.

Razorback Electronics Research Lab Announcement

(Submitted by Scott Mason) The Razorback Electronics Manufacturing Laboratory (REM Lab) is a research facility located in the Engineering Research Center of the University of Arkansas. The lab is dedicated to advancing the current state of the art in semiconductor manufacturing scheduling research and to preparing trained engineers to enter this challenging field in the real world. Please visit the lab at http://www.uark.edu/~remlab.

FabTime welcomes the opportunity to publish announcements for individuals or companies. Simply send them to Jennifer.Robinson@FabTime.com.

FabTime Recommendations

Cycle Time Improvement Paper: There's a paper on cycle time improvement for photo in a recent issue of IEEE Transactions on Semiconductor Manufacturing that you might find interesting. The full reference is: E. Akcali, K. Nemoto, and R. Uzsoy, "Cycle-Time Improvements for Photolithography Process in Semiconductor Manufacturing," *IEEE Transactions on Semiconductor Manufacturing*, Vol. 14, No. 1, 48-56, 2001. This paper investigates the effects of various process control mechanisms for photolithography on the cycle-time at the process and on the overall fab via a simulation study (using a SIMAN model).

Book Recommendation: In honor of the Duke Blue Devils (2001 NCAA Men's Basketball Tournament Champions), FabTime's book of the month for April is Leading with Heart: Coach K's Successful Strategies for Basketball, Business, and Life, by Mike Krzyzewski and Donald Phillips (see full review at http://www.fabtime.com/CoachK.htm). This book contains some nice pointers regarding team leadership, and some fun basketball trivia as well.

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