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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Contributors: Scott Mason (University of Arkansas); V. A. Ames (Productivity System innovations); Phil Fontes (NEC Electronics)

Welcome

Happy New Year, and welcome to Volume 4, Number 1 of the FabTime Cycle Time Management Newsletter. We have several announcements this month. First of all, we're very pleased to announce that AMD's Fab25 has upgraded to the latest version of our cycle time management software, and is working with us on implementing the new "quality moves" metric that we described last month. We also call your attention to our newly re-designed website. We think that you'll find it easier to find the information that you need. Finally, we have announcements from Scott Mason (University of Arkansas) and V. A. Ames (Productivity System innovation).

In this month's subscriber discussion forum we have responses from Phil Fontes (NEC Electronics) and two other anonymous subscribers to our recent topics regarding operator productivity. Our main article this month is about quantifying variability in wafer fabs. We have talked many times about how wafer fab cycle time can be reduced by reducing fab variability. In this article, we describe a metric for quantifying this variability (coefficient of variation), and discuss how to calculate it for times between arrivals and for process times. We believe that by measuring variability, particularly relative levels of variability at individual tool groups and operations, readers will be better able to identify potential improvement areas.

Thanks for reading!—Jennifer

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Community News/Announcements

AMD Fab 25 Upgrades to Version 4.0 of FabTime Cycle Time Software, Begins Project with FabTime on Quality Moves Metric

Menlo Park, CA. December 11, 2002 - FabTime Inc. today announced that AMD Fab 25 in Austin, Texas has upgraded to Version 4.0 of FabTime's cycle time management software for wafer fabs. Fab 25 has been in volume production of 32 Megabit and 64 Megabit Flash memory devices using 0.17 micron technology since May of 2002, and has begun implementation of 0.13 micron technology.

"FabTime has been very responsive to our development requests," said Mike Hillis, Fab25 Cycle Time and Line Yield Improvement Manager. "Our FabTime users have quickly taken advantage of Version 4.0, particularly its ability to slice and re-slice fab performance metrics to highlight trends and trouble spots."

AMD and FabTime have also begun a project to implement a new performance metric known as "quality moves." Quality moves are designed to measure, on a shift-by-shift basis, the best performance that can be achieved given the shift's initial WIP profile and resource availability. "Long-term goals are useful," said Mike Hillis, "but short-term conditions can make those goals impossible to achieve, or not aggressive enough, for a given shift. The quality moves metric gives us a daily target that is meaningful to shift managers, because it recognizes short-term constraints."

FabTime is designed to give wafer fab managers and their staff the information that they need, in real-time, to run their fabs effectively. FabTime extracts operational data from the fab manufacturing execution system (MES) every five minutes, and processes this data into a SQL Server data warehouse. Users can then access a comprehensive system of cycle time-related charts and alerts via a web browser from anywhere within the corporate Intranet. More information about FabTime's software is available at www.fabtime.com/software.htm.

FabTime Website Re-Design

FabTime is pleased to announce a complete re-design of our public website, www.FabTime.com. Top-level sections now describe our three primary offerings: cycle time improvement consulting, cycle time management training, and our FabTime software. Other sections include the Newsletter (with abstracts to past issues), our Library (including bibliographies, conference directory, tutorials, and downloadable technical papers), and the standard About, Contact, and Search areas. We think that you'll find the new website easier to navigate, to find the information that you need. We welcome your feedback.

Doctoral Fellowship in Semiconductor Wafer Fab Scheduling at the University of Arkansas

Scott Mason, Director of the Razorback Electronics Manufacturing Laboratory at the University of Arkansas, submitted the following announcement. "I am pleased to announce that I was recently awarded a Distinguished Doctoral Fellowship position for a new PhD student to work with me in my semiconductor wafer fab scheduling research. This fellowship is for $30,000 per year for up to 4 years. Requirements of the PhD student include course work, independent research, and potentially teaching a maximum of one industrial engineering course per fall and spring semester."

More information, including required

applicant qualifications, is available at http://remlab.ineg.uark.edu. Interested students should contact:

Scott J. Mason, PhD, PE
Asst. Professor of Industrial Engineering
Graduate Studies Chair
mason@uark.edu

Job Change Announcement - V.A. Ames

V.A. Ames submitted the following announcement. "I am longer working at Applied Materials and have decided to start my own consulting business called "Productivity System innovations (PSi)." The business will focus on improving manufacturing productivity by identifying and eliminating equipment performance inefficiencies and variations. This applies to any type of manufacturing facility or equipment supplier.

A four-step improvement process is designed to provide fast results and high ROI by enhancing skills, increasing productivity, and decreasing cycle time and costs. I am also able to help with TPM and OEE implementation and the definition of equipment performance reporting, especially in the area of e-diagnostics.

I can be reached at 512-762-5459 or by email at productivitysi@austin.rr.com or vames@austin.rr.com. It would be great to hear from all my old friends and acquaintances that subscribe to your newsletter."

FabTime welcomes the opportunity to publish community news and announcements. Simply send them to Jennifer.-Robinson@FabTime.com.

Subscriber Discussion Forum

The Impact of Staffing on Cycle Time

Philip Fontes of NEC Electronics wrote not to address the specific questions that we asked in Issue 3.09, but because he had questions about two aspects of last month's article. First, he raised the point that the values that we gave in our example as the M/M/3 queueing results (for the case without operator constraints) did not quite match what one would get from entering the values in the Queueing ToolPak spreadsheet add-in that we recommended. The reason for this discrepancy was that we did not use the Queueing ToolPak for this example, but instead used our Operating Curve Generator spreadsheet. There is a slight difference in the approximations used by these different tools, and we also rounded slightly to use a value already included in our operating curve spreadsheet. So, we thank Phil for his careful attention to the results, and we wanted to explain this here, in case anyone else was puzzled.

Phil also raised this issue: "I am perplexed with the notion of "...forced idle time drives up equipment utilization." That seams so counter-intuitive, because you don't get more wafers out when your tool sits idle due to operator unavailability to load/unload lots. People usually equate increased productivity with higher tool utilization. Of course, the only way to get a higher ratio is to take some time out of the denominator: (Productive Time) / (Productive Time + Standby Time.) So, the point of contention becomes, "why don't you include forced idle time in Standby time?" Since Line Maintenance has the responsibility of keeping the tools "available", and Production has the responsibility of keeping the tools "staffed", it seams unfair to skew [increase] utilization numbers when Production has not made greater use of the tool's "available" time."

FabTime's response to this point was that for cycle time we're interested in looking at the situation from the lot's point of view. From the lot's perspective, that forced idle time is not standby time. The lot is waiting during that time, just as if the tool was unavailable. And this is what drives up cycle time. For us, it's not a question of fairness between maintenance and production; it's a question of what definition of utilization is the one that drives cycle time. Consider the extreme case, where you need any operator, but the operator is never available during the tool's available time. Then the lots can never be processed, and the cycle time increases to infinity, just as in the case where you have no equipment idle time.

In response to this, Phil suggested the following: "If forced-idle time is only expressed in increased utilization numbers, it would definitely mask the opportunity production has in improving staffing effectiveness or increasing staffing levels for greater output capability. This brings me back to a thought I had about trying to break-out "good" idle time (no lots available) vs. "bad" forced idle time (work, but no operator available) for a better view of PEE (Production Equipment Efficiency) instead of reporting the more readily calculated OEE."

We think that Phil makes two excellent points here. The first is that it's all very well to include forced idle time due to no operator as part of tool utilization (not as part of regular standby time), but it's still important to measure this time, so that it can be reduced. This also ties back in nicely to Phil's second point, that by understanding "good" idle time vs. "bad" idle time we can tie back in to the Production Equipment Efficiency (PEE) calculations that we discussed back in Issue 3.01.

Wafer Moves Per Operator

In the last newsletter article, David Chia of Chartered Semiconductor Manufacturing asked: "Along the discussion on operator staff impacting capacity, I have a question on "what is the typical wafer moves per operator expected?" There is a measurement on how we staff operators verses number of equipment etc etc."

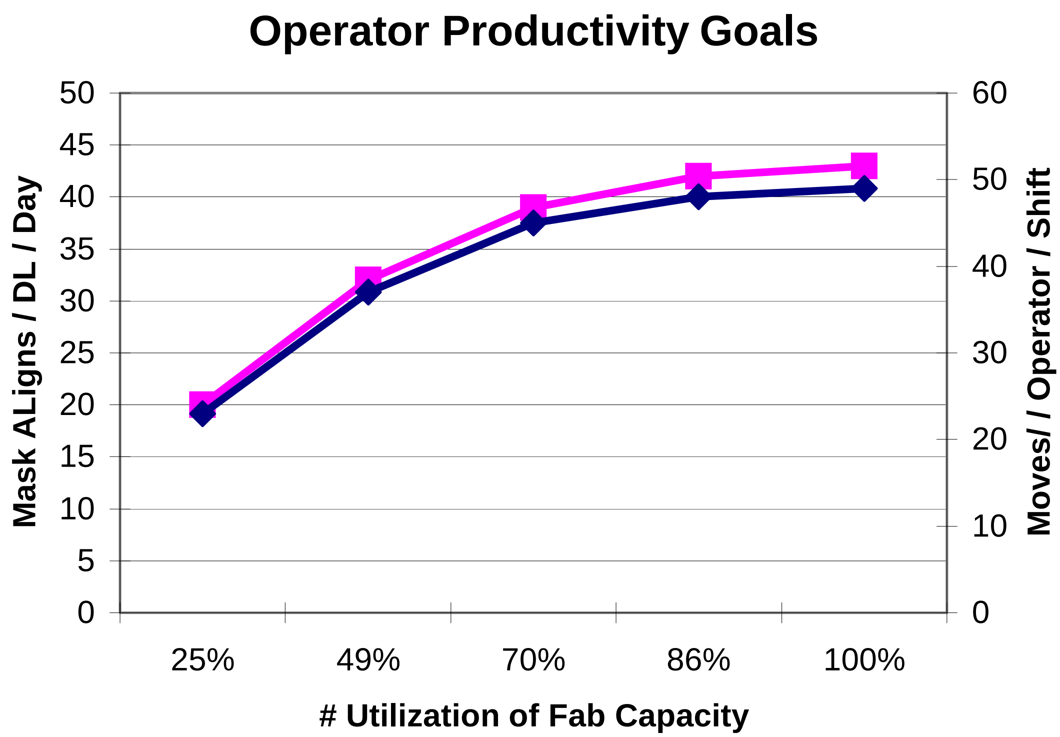
One of our subscribers has taken the trouble to respond in detail to this question. We think that you'll find it useful. He raises the excellent point that the answer to this question often depends on fab loading, as illustrated below.

"We find our Operator productivity is heavily influenced by the % Utilization of our Fab capacity. We typically plan Operator requirements (and track overall average productivity) based on Mask Alignments per Operator per Day. I've converted this to equivalent Lot Step Moves per Operator per Shift.

% Utilization of Fab Capacity	Mask Aligns / Operator / Day	Lot Step Moves / Operator / Shift
25%	20	23
49%	32	37
70%	39	45
86%	42	48
100%	43	49

where

Mask Aligns / operator / day = Total daily Mask Alignments (Wafers through Steppers) / Total Operators on payroll.



Lot Step Moves / operator / shift = Number of "Track-ins" per operator per shift = Total (lot) Step Moves on a Shift / Total Operators on a Shift.

Operators = Direct Labor = all Manufacturing Non-Exempts (includes Test Wafer associates, reticles group, manufacturing trainers, etc.).

These are the Planning numbers. Typically, unless we're in a ramp-up situation, we find that our average productivity is about 10% below our Planning goal."

Workload Analysis and Productivity Improvement Using Video Footage

Another subscriber brought to our attention an interesting approach to staffing analysis, presented in a paper from the ISSM 2002 Conference (International Symposium on Semiconductor Manufacturing), in Tokyo, Japan. Production Engineers at FASL in Japan used video footage to analyze manpower requirements. The full reference and abstract are included below. This paper is not available from FabTime. You can purchase the complete conference proceedings on CD-ROM from the ISSM website (http://www.issm.com/) for 10,500 Japanese Yen (about $87 US).

Y. Ishii, "Workload Analysis and Productivity Improvement Using Video Footage," Proceedings of the 2002 International Symposium on Semiconductor Manufacturing (ISSM2002), Tokyo, Japan, 2002.

Abstract: In the past, our calculation of the manpower required for production plans was not based on any theory. However, current needs to reduce costs, driven by changing markets and stiffening competition, have made it necessary for us to indicate manpower requirements for production in numeric values on the basis of theory. We initiated analysis of every type of operation that we had not previously been able to evaluate with numeric values.

Quantifying Wafer Fab Variability

Introduction

Two things primarily drive cycle time in a wafer fab: utilization and variability. When there is any variability in the fab (and there always is some variability), cycle time through each tool group (and hence through the fab) will tend to increase with utilization. This increase is non-linear, and grows more rapid as utilization approaches capacity. The result is the familiar operating curve of cycle time vs. utilization. People who run fabs are well aware of this phenomenon, and they try to leave a buffer of slack capacity (standby time) on most tools, to avoid that steep part of the operating curve.

Variability affects the shape of the operating curve. Increased variability in either times between arrivals or in process times will tend to drive up cycle time. A relatively inexpensive way to reduce fab cycle times, then, is to decrease variability. Decreasing variability will move the operating curve down, and let you operate with a smaller capacity buffer, at the same overall cycle time, without paying for extra tools or operators.

We have talked in earlier issues about some of the things that contribute to wafer fab variability: unreliable equipment, batch processing at furnaces, setups, batch lot releases, reentrant flow, product mix, and operator unavailability, to name a few. What we have not talked about in detail is how to measure wafer fab variability. Since the first step to improving something is to measure and understand it, in this issue we will discuss how to quantify the amount of variability in your fab, using data from your MES.

Arrival Time Variability vs. Process Time Variability

In our cycle time management class, we ask people which they think hurts cycle time more: process time variability or variability in the time between arrivals. Most people think that arrival process variability is bigger culprit. In fact, if you have the same amount of variability in the times between arrivals that you have in the process times, then they will have the same impact on cycle time. This comes from the following formula, where X-factor is actual cycle time divided by theoretical (raw) process time.

XFactor ~= 1 + [Utilization/(1-Utilization)] * [Variability Factor]

where Variability Factor is the sum of arrival variability and process time variability

Variability Factor = $(CV_a^2 + CV_p^2)/2$, where

CV_a = Coefficient of variation for inter-arrival times (the time between arrivals)

CV_p = Coefficient of variation for process times

Coefficient of Variation

The above formula means that these two coefficients of variation (CV_a and CV_p) should be excellent indicators of the amount of variability in your fab. You can calculate both coefficients of variation for the entire fab, or you can calculate them at a lower level (by area, operation, toolgroup, tool, etc.). Coefficient of variation is a statistical measure that you can use to get a sense of how much variation there is in a set of individual values. The calculations are very simple.

Coefficient of Variation = Standard Deviation / Average

Standard deviation measures how widely values are dispersed from the average value, and average is then used to scale the values for comparison in coefficient of variation.

Arrival Process Variation

Times between arrivals are relatively easy to record from MES data. You simply record the "time in" for each lot, and compare that to the "time in" for the most recent previous lot. You can do this looking at arrivals to all operations, or you can be more specific, and only record "time in" for arrivals to a particular operation.

For example, suppose that we have the following series of lot arrivals to an individual operation:

Time	Lot Number
6:00	1
7:00	2
8:00	3
9:00	4
10:00	5

The series of times between arrivals is:

- Time between Lot 1 and Lot 2 = 1 hr.
- Time between Lot 2 and Lot 3 = 1 hr.
- Time between Lot 3 and Lot 4 = 1 hr.
- Time between Lot 4 and Lot 5 = 1 hr.

And we have the series of interarrival times {1, 1, 1, 1}

In this case, the standard deviation of the interarrival times is zero (because the values are not at all dispersed - they are all the same), the average value is one, and hence CV_a = 0 / 1 = 0. This is the (highly unlikely) no variability, or constant arrivals, case.

Suppose, however, that the times between arrivals are much more variable, like the following:

Time	Lot Number
6:00	1
6:05	2
10:00	3
14:30	4
14:40	5
14:57	6
16:12	7
22:18	8
01:45	9
01:50	10

Then the series of times between arrivals, or interarrival times, is:

- Time between Lot 1 and Lot 2 = 5 min.
- Time between Lot 2 and Lot 3 = 3 hours, 55 min. = 235 min.
- Time between Lot 3 and Lot 4 = 4 hours, 30 min. = 270 min.
- Time between Lot 4 and Lot 5 = 10 min.
- Time between Lot 5 and Lot 6 = 17 min.
- Time between Lot 6 and Lot 7 = 1 hour, 15 min. = 75 min.
- Time between Lot 7 and Lot 8 = 6 hours, 6 min. = 366 min.
- Time between Lot 8 and Lot 9 = 3 hours, 27 min. = 207 min.
- Time between Lot 9 and Lot 10 = 5 min.

And we have the series of interarrival times {5,235,270,10,17,75,366,207,5}.

Plugging this into Excel, we get for Standard Deviation (use the =STDEV function) 138.6, and for average 132.2.

Then CV_a = 138.6/132.2 = 1.05. This means that these interarrival times are slightly more variable than an exponential distribution. An assumption commonly made in queueing models is that interarrival times are exponentially distributed, and so CV_a = 1.0.

What we have observed from calculating the operation-level coefficient of variation of interarrival times for data from full-fab simulation models is that the coefficients of variation can actually be much larger than 1.0. We have seen them as high as 4.0 for early operations, when lots are released into the fab in large batches. Interarrival times can also be variable downstream from batch tools. Consider an extreme case, where a large, one-of-a-kind batch tool is the only tool feeding a subsequent non-batch operation. The arrival pattern might look something like this:

- Batch of 8 lots arrives
- 21 hours go by
- Another batch of 8 lots arrives
- 24 hours go by
- Another batch of 8 lots arrives
- 23 hours go by

The time between arrivals from one lot to the next within each batch is zero, and the sequence of interarrival times looks like this {0,0,0,0,0,0,0,21,0,0,0,0,0,0,0,24,0,0,0,0,0,0,0,23}. For this sequence (using Excel to calculate), the standard deviation is 7.7 and the average is 2.8, for a coefficient of variation of 7.7/2.7 = 2.7 - much larger than the often-assumed 1.0.

Process Time Variation

Process time variation is actually somewhat harder to capture. In the simplest case, we can calculate this from MES transactions:

Process Time = "time out" - "start process time"

for lots completing processing on each tool. We can then compute the coefficient of variation for the series of process time values. However, now we have a problem of how to include things like downtime, setups, operator delays and waiting for monitor wafers. From the lot's perspective, once the lot reaches the front of the queue and there are no lots currently being processed on the tool, everything up to "move out" looks like process time, not queue time. For a real-world example of this problem, suppose that you wait in line for 15 minutes at airport check-in, and you are at the front of the line, and there's only one gate agent serving your line. Now suppose that after the gate agent finishes helping the person in front of you, he or she leaves for a 10-minute break. That 10 minutes isn't really queue time - you aren't waiting for any other customers to be processed. The 10 minute delay is pretty much part of your process time.

To account for this when we estimate process time variability in the fab, we would like to have some sort of observed process time calculation that computes the time from when a lot is at the front of the queue, and ready to be processed (and the server is not busy processing another lot), until the lot finishes processing. This gets tricky, however. For example, suppose that the machine is not processing, but it is down for PM, and Lot #1 arrives. We should start the clock ticking for Lot #1's observed process time (if Lot #1 is the only lot in queue). But suppose that before the PM is finished, Lot #2 arrives, and Lot #2 is a hot lot. We need to turn the observed process time clock for Lot #1 off, and start the one for Lot #2. So later, when we ultimately process Lot #1, would that early queue time be counted as part of the observed process time for Lot #1? Or what about when a lot arrives that could be processed on either of two tools, but both tools are down, with no other lots in queue? Do we need to assign the lot to one of the two tools now, to simplify the calculations?

Jacobs et. al. (see reference below), propose an algorithm for computing the mean and coefficient of variation of an effective process time (which they call EPT) which takes into account these capacity losses, and gives results that can be used in standard queueing formulas such as the G/G/m approximation. Their method addresses some of the complexities described above, but it is beyond the scope of this newsletter to go through their method in detail.

Overall, our recommendation is that you can calculate the coefficient of variation of the actual process times (move out time - start process time), but you should be aware that this is very much a lower bound on the process time variability. This will capture variability in the process times due to product mix/reentrant flow (on one visit the process time is 10 minutes, but on the next visit the process time is 12 minutes). However, this method will not account for other capacity losses at the tool, such as downtimes, setups, operator delays, etc. If you want to estimate that variability, you can use a method like the one described by Jacobs et. al., use a full-scale factory simulation model (in which you explicitly model the different sources of variability), or come up with a method on your own for in some way accounting for this addition observed process time.

Summary

Variability contributes to observed cycle times in all wafer fabs. Reducing this variability is a relatively low cost way to improve cycle time, and potentially improve your company's bottom line. You will find it easier to focus your variability reduction efforts if you measure the actual variability in your fab. Coefficient of variation of interarrival times (CV_a) and coefficient of variation of process times (CV_p) are good indicators of the amount of variability in the fab. Measuring CV_a and CV_p at the tool group or operation level will show you where in the fab variability is particularly a problem. Measuring them at the factory level over time will provide an overall benchmark of whether or not your variability reduction efforts have been successful.

Recommendations

We recommend that you begin by measuring coefficient of variation of interarrival times to specific toolgroups or operations in your fab. CV_a is fairly easy to calculate from MES WIP transactions, and will highlight locations in the fab where arrival variability is likely driving up cycle times. Of course the accuracy of the results will depend on how reliably your fab logs move transactions (if your operators let lots collect into groups, and then log a whole bunch of transactions at once, CV_a from your MES data will look high).

Calculating coefficient of variation of process times will be more difficult, because of the impact that certain capacity losses have on the effective process times observed by individual lots. As a first pass, you can calculate CV_p based only on the process time itself. This will provide a lower bound on the amount of process time variability. Other methods exist for estimating the sequence of effective process times, and will likely demonstrate much higher values for CV_p.

Closing Questions for FabTime Subscribers

Do you measure variability in interarrival times or process times for your fab? If so, do you have this set up as a standard report from your MES, or is it something that someone calculates through custom queries on an occasional basis?

Further Reading

- P. Gaboury, "Equipment Process Time Variability: Cycle Time Impacts," *Future Fab International*, Issue 11. Available from www.mksinst.com/pdf/IPCeptv.pdf.

■ J.H. Jacobs, L.F.P. Etman, E.J.J. van Campen, J.E. Rooda, "Quantifying Operational Time Variability: the Missing Parameter for Cycle Time Reduction," *Proceedings of the 12th Annual IEEE/SEMI Advanced Semiconductor Manufacturing Conference*, Munich (2001). Abstract available at yp.wtb.tue.nl/showabstract.php/1885

■ A. Schoemig, "On The Corrupting Influence Of Variability In Semiconductor Manufacturing," *Proceedings of the 1999 Winter Simulation Conference*, 1999. This paper shows how variability (in the form of the distribution of tool downtime events) influences the operating curve of a simulated wafer fab. Longer or more variable downtime events, even at the same overall percent time down, drive up cycle time. You can download this paper free from http://www.informs-cs.org/wsc99papers/prog99.html. The paper is not available directly from FabTime.

■ S. Sokhan-Sanj, G. Gaxiola, G. T. Mackulak, and F. B. Malmgren, "A Comparison of the Exponential and the Hyperexponential Distributions for Modeling Move Requests in a Semiconductor Fab," *Proceedings of the 1999 Winter Simulation Conference*, 1999. This paper focuses on the influence of variability in designing an automated material handling system. Among other results, the paper compares the standard deviation of moves per hour in an actual wafer fab vs. a simulation wafer fab with exponential time between creation events. You can download this paper free from http://www.informs-cs.org/wsc99papers/prog99.html. The paper is not available directly from FabTime.

For more on coefficient of variation, see the text Factory Physics, by Hopp and Spearman. You can find a review, and a link to this book on Amazon, at www.FabTime.com/physics.htm.

FabTime Recommendations

The Zero Saga & Confusions with Numbers

This site explains the history, value of the concept, and symbol of zero, and its role in mathematics. The site is maintained by a professor at the University of Baltimore. You can find the site at ubmail.ubalt.edu/~harsham/zero/ZERO.HTM. It was recommended by NetLibrary.

Slipstick Systems Exchange and Outlook Solutions Website

We don't know about you, but we use Microsoft Outlook a LOT. Pretty much all day every day. Occasionally we run into quirky behavior. Or we fear running into quirky behavior if we upgrade to a new version of Outlook, or when we changed from running standalone Outlook to running Exchange Server. Slipstick Systems is a software/consulting company that focuses exclusively on Outlook and Exchange, and has been doing so since 1994. The website contains news about Outlook/Exchange (patches, product announcements, etc.), as well as links to software utilities, how to articles, etc. Slipstick's founder, Sue Moser, has published a number of books on Outlook, and makes much of her expertise available at no charge on the Slipstick website. We use this website most frequently when we want to know "Isn't there an add-in/utility program that will make Outlook do xxx?" You can find Slipstick at www.slipstick.com.

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Kav Project (1)
Kaveri Corporation (1)
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OPTUM-IES (2)
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SAE Magnetics (2)
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SAMES (1)
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Sarnoff Corporation (2)
SAS (2)
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SUNY-Binghamton (1)
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Süss MicroTec AG (1)
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Technische Universitat Ilmenau (1)
TEFEN USA (1)
Teradyne (1)
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Toppoly Optoelectronics (1)
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Toyota CRDL (1)
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TriQuint Semiconductor (8)
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Unitopia Taiwan Corporation (1)
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University of Aizu - Japan (1)
University of Arkansas (1)
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University of Cincinnati (1)
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Voltas Limited (1)
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WaferTech (15)
Win Semiconductor (1)
Wright Williams & Kelly (4)
Xerox Brazil (1)
X-FAB Texas, Inc. (3)
Yonsei University (1)
Zetek PLC (1)
ZMC International Pte Ltd (2)
Unlisted Companies (13)

Consultants

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Javier Bonal
Steven Brown
Stuart Carr
Alison Cohen
Paul Czarnocki
Doreen Erickson
Scott Erjavic
Greg Fernandez
Ted Forsman
Navi Grewal
Cory Hanosh
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