FabTime Cycle Time Management Newsletter
Volume 8, No. 4 May 2007

FabTime Cycle Time Management Newsletter

Information

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

Publisher: FabTime Inc. FabTime sells cycle time management software for wafer fab managers. New features in the software this month include support for link-based login, so that following a link logs the user into FabTime as a particular user, and allows them to navigate within FabTime.

Editor: Jennifer Robinson

Contributors: Jason Wang (ProMOS Technologies); Bart Lemmen (NXP); Tom Lambe (ATDF)

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Welcome

Welcome to Volume 8, Number 4 of the FabTime Cycle Time Management Newsletter! We hope that May finds most of you enjoying some summer weather. I've been very busy with a sequence of cycle time management classes that I'm conducting for one company; while Frank is hard at work on installation projects for our newest customers (we recently started working with our 13th customer site). In this issue we have a software user tip of the month about copying user accounts, and two subscriber responses to last month's issue about estimating operation-level cycle times. It seems that we're not alone in having been thinking about that.

In our main article this month, we address sources of variability in wafer fabs. Variability is one of the main causes of fab cycle time. Variability affects the shape of the operating curve of cycle time vs. tool utilization. By reducing variability, we can move the knee of the operating curve for a fab, achieving a lower cycle time at the same throughput rate. Variability reduction is a relatively inexpensive way to improve cycle time, because it does not require the purchase of capital equipment, or any reduction in starts. However, in order to reduce variability in your fab, you need to be able to identify the specific sources of variability. In this article, we review some of the major sources of variability in fabs, and suggest several general methods for reducing it. We then discuss in detail metrics that you can use for quantifying and identifying specific variability problems in your fab. We hope that you will find this article useful. As always, we welcome your feedback.

Thanks for reading!—Jennifer

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Community News/Announcements

FabTime welcomes the opportunity to publish community announcements. Send your announcements to newsletter@-FabTime.com. There are no announcements in this issue

FabTime User Tip of the Month

Clone a User Account

Here are the steps required to make a copy of a user account. This will copy all account preferences, including any home page charts that have been configured. Only your site system administrators (people who have the admin account password) will be able to copy user accounts.

1) Login to FabTime as the system administrator.

2) Click on "User" in the FabTime navigation bar. This brings up a list of users.

3) Locate the relevant row for the account to be copied in the list of users ("username"). Click on the "Copy" link in this row. That duplicates the account and creates a login "username (Copy)", then redisplays the list of users.

4) Locate the "username (Copy)" account in the list of users, click on the "Edit" link in this row.

5) That brings up the user settings page for the copied account. Change the Login ID to the login name for the new account ("new account"), fill in the username and email address, and change any other account preferences if necessary, then click "Save".

6) This brings up the list of users again. Scroll down to confirm that "new account" is listed as a user.

Then login to FabTime as "new account" (use the existing password for the previous account, that gets copied with the account data). You can change password, clean up charts, modify the email address etc.

If you have any questions about this feature (or any other software-related issues), just use the Feedback form in the software.

Subscriber Discussion Forum

Issue 8.03: Operation-Level Cycle Times (1)

Jason Wang from ProMOS sent in the following comments: "ProMOS Inc (DRAM Manufacturer based in Taiwan) has the following procedure to estimate operation-level cycle times:

1. First, we use historical data to estimate actual Raw Process Time (RPT). The RPT is obtained from our Equipment Automation Program (EAP), which automatically records move-in / move-out time of lots, a process that is much more accurate than one which is done by operators.

2. For forecast purposes: we multiply different x-factors with RPT to derive fab cycle times. So this method is somewhat between the historical data model and the queueing model.

3. For dispatching purposes: we divide our process flow into four sections, allowing bottlenecks to have larger cycle time buffers. This method is similar to your historical model."

Issues 8.03: Operation-Level Cycle Times (2)

Bart Lemmen of NXP, working in the Crolles2 Alliance of Freescale, NXP and ST in Crolles France, submitted the following feedback to last month's main article about estimating planned operation cycle times.

"Typically cycle time models need to satisfy the needs of multiple different 'customers'. To all customers the models need to provide a statistically accurate estimation for WIP lots. The needs can be for internal use (e.g. outs; median based) or external use (e.g. commitment; x-sigma based). Maintaining a theoretical cycle time model to match all needs can be as time-consuming as maintaining a complex capacity model and often still lacks accuracy in its' projections. Besides the generally underestimated cycle time due to incomplete modeling, it has other drawbacks such as exclusion of actual line-balance influences. Simulation models can partially compensate for those effects but still have the maintenance aspect. From my experience, the best cycle time estimate is based on historical performance.

A proven history-based method for lot cycle time projection uses the distribution per operation to provide a relative trend, i.e. operation x is slower than operation y, and uses the distribution on dynamic cycle time to scale the trend towards an appropriate lot cycle time. The used methods to aggregate fab-performance towards a trend (cycle times per operation) are based on statistical methods. Amongst the history-collected values is a 20th percentile operation cycle time for estimating a lower boundary without line-balance influence and a 50th percentile cycle time (hold excluded) for estimating a median performance that includes some line-balance influence. Note that the 20th percentile represents the cycle time value achieved by 20% of all lots that passed the operation. The database resulting from the history collection process can be used for operation cycle time (variance) analysis, but also for WIP lot projections.

The average operation cycle time lacks statistical support for usage in WIP lot projections. As mentioned in your article the sum of all 50th percentiles for a lot does not provide the correct total. The latter however can be solved by applying a day per mask based correction.

For short-term use, such as predicting your future holds to prepare for the weekend, no day per mask scale-factor is needed: simply use the correct percentile for your short-term projection. For very short-term projections (few days), the 50th percentile might be most correctly satisfying the needs. For less short-term (weekly projections), the 60th percentile compensates for the underestimating aspects of a 50th percentile. For mid-term use, such as outs projection, the lot cycle time needs to result in a days per mask close to the actual dynamic performance. If the 50th percentiles add up to 1.2 day per mask level for a to be started lot and actual dynamic cycle time performance is 1.5 day per mask you simply multiply each operation cycle time by 1.5/1.2 to have an accurately estimated expected out date that includes your current line-balance. If you wish to exclude your current line-balance, simply use the 20th percentile value: a higher scale-factor will be applied automatically when targeting the same 1.5 day per mask goal.

Thanks to Jennifer and the others for coming up with another good topic for the FabTime newsletter!"

Sources of Variability in Wafer Fabs

We have talked before (see issue 6.05) about the three fundamental drivers of fab cycle time: tool utilization, number of qualified tools at each operation, and variability. We can work to improve tool utilization by increasing equipment uptime, or, in some cases, adding capacity (as discussed in Issue 7.06). We can mitigate the impact of variability by identifying sources of variability in the fab, and working to eliminate them. And we can increase the number of tools that are qualified for each operation by minimizing the number of process restrictions in the fab, and ensuring that every operation has at least two qualified tools. In this issue, we will discuss common sources of variability in fabs, and methods for identifying specific variability problems. In a future article we will discuss the impact of process restrictions on fab cycle time.

Background

The operating curve for a toolgroup is a graph of cycle time x-factor (cycle time divided by theoretical cycle time) vs. tool utilization. The operating curve is generally shaped like Cycle Time X-Factor = 1 / (1 - utilization), reflecting the fact that as utilization approaches 100%, cycle time becomes very large. The exact shape of the operating curve, however, is a function of the amount of variability present. The more general formula for the shape of the operating curve, for a one-of-a-kind tool, is:

Cycle Time X-Factor = 1 + (Utilization/(1 - Utilization))*(Variability Factor)

where the variability factor is the sum of variability in arrivals to the tool and variability in process times. When the variability factor is zero, the entire second term drops off, and we have Cycle Time X-Factor = 1. That is, the only time we have perfect cycle times is when we have no variability. The closer the utilization is to 100%, the more of an impact the variability factor has on the cycle time.

The form of the variability factor is:

$(CV_a^2 + CV_p^2)/2$

where CV_a is the coefficient of variation of the arrival process, and CV_p is the coefficient of variation of the process times. Coefficient of variation is a statistical measure for a set of values, reflecting how widely dispersed they are, normalized by the average. That is, coefficient of variation is equal to the standard deviation of the set of values divided by the average of the set of values. Standard deviation reflects how widely a set of values is dispersed from an average. The higher the coefficient of variation in arrivals, the higher the cycle time will be. Similarly, the higher the coefficient of variation in process times, the higher the cycle time.

General Sources of Fab Variation

There are many factors in fabs that contribute to high levels of variation in both process times and arrival times at tools. Some of these are listed below:

Variability that affects how lots get processed on tools

- Different recipes run on the same tool (this stems from product mix and from the reentrant nature of our process flows)
- Setups
- Equipment failures and maintenance events
- Quals
- Engineering time on the tools
- Operators (not being available to load or unload)
- Operator decisions about what to process next (e.g. to drive up their own moves)
- Scrap (because it changes the lot size)
- Rework
- Other lot size variation (from product mix)
- Inspections
- Time constraints between process steps (because it can lead to the re-processing of lots, requiring additional process time)
- Technicians (not being available to fix a problem)
- Hot lots (especially hand carry lots, when tools are held idle)

Variability that affects how lots arrive at tools.

- All of the above, because what leaves one tool goes downstream to another tool. Plus:
- Lots going onto and coming off of hold
- Batch transfer between steps (carts that can hold multiple lots at one time)
- Automated material handling (because of the travel time to move through the system, and the need to use dispatching to decide which lot to move to each tool next)
- Batch processing (e.g. furnaces that can process more than one lot at one time)
- Lot release into the fab (e.g. releasing lots only once per day into the line).

Some General Statements about the Likely Sources of Variability in Your Fab

While we can't know, without looking at the data, exactly which of the above sources of variation are causing problems for your fab, we can make a few general statements.

- If you are holding tools for hand carry lots, then you are losing capacity on those tools, and this is causing extra cycle time in your fab. The best way to minimize this effect is to minimize the number of hand carry lots you have in the fab at one time (one lot in the fab at one time is our recommendation), and to only hold one to two steps idle in advance of the hand carry lot.

- If you have any process restrictions that cause operations to only be able to be run on one tool, then these process restrictions are causing cycle time. You may need to accept those restrictions, if they are important for yield reduction. But if it's just a matter of getting more tools qualified, then you should go ahead and get a second tool qualified. We can state with near certainty that the process restrictions are driving up your cycle time. This isn't variability per se, but having the process restrictions makes you much more vulnerable to the variability at each operation.

- If you transfer lots between steps using carts, and those carts can hold more than one lot at a time, then your operators are introducing variability in arrivals by batching lots together at carts.

- If you have any batch processing (where you process multiple lots at the same time on one tool, such as a furnace), then your batch steps are almost surely contributing arrival variability downstream. The best way to minimize this effect is to run the batches as small as possible (subject to cost and processing constraints).

Quantifying the Effect of Variability

The above general suggestions are all very well, but how do you determine exactly which sources of variation are causing the biggest cycle time problems in your fab? The short answer is that you need to collect data. In this section, we discuss possible data sources to use to quantify the variability in your fab. Most of the metrics described are available in FabTime's software. It should also be possible to determine most of them from standard MES data, possibly exported into Excel.

Coefficient of variation of interarrival times to tool groups: This is measured by starting the clock each time a lot arrives, and stopping with an observation of interarrival time once the next lot arrives. The sequence of the interarrival times (times between lot arrivals) can then be put into Excel, with coefficient of variation calculated as standard deviation of the set of interarrival times divided by average of the set of interarrival times. We discussed this in more detail in Issue 4.01. Toolgroups with a high coefficient of variation of arrival times are often downstream from batch tools, or downstream from tools with highly variable availability. Note: If you are analyzing a toolgroup where lots tend to arrive in batches, then you should calculate the coefficient of variation for time between the batch arrivals, and also the coefficient of variation of the batch size. The arrival CV is an indicator that arrival variability is likely contributing to the tool's cycle time. This is especially true at toolgroups that have moderately high utilization (70% to 90%). Toolgroups that always have a queue in front of them are less subject to arrival variability, in a sense, because newly arriving lots always go to the rear of the queue. However, it's not practical to maintain a constant queue in front of all of the tools in the fab (because that queue translates to longer cycle times through the tool). In general, any toolgroup that is sometimes idle due to not having WIP in front of it will experience better per-visit cycle times if the arrival variability can be reduced.

Coefficient of variation of process times at tool groups: The simplest way to estimate process time variability is to take the sequence of actual observed process times for the toolgroup, and calculate the coefficient of variation (as above). This gives a lower bound on the variability in lot to lot process times, as it does not capture things like setups, quals, operators not being there to load the tool, and equipment downtime. It mainly captures variation from running different recipes on the same tool, lot size variation, and operators not being available to unload the tool. A more detailed method of estimating process time variation was developed by researchers at the Technical University of Eindhoven. You can find the reference below under Jacobs et. al. Toolgroups that have a high degree of process time variability will most likely have higher per-visit cycle times than similarly utilized tools with less process time variability.

Coefficient of variation of productive time: A combined indicator that captures both arrival variability and uptime variability by toolgroup is the coefficient of variation of the average productive time across tools in the group. To measure this, for each shift, record the percent of time that each tool spends busy processing wafers and average that across all tools in the toolset. Then calculate the coefficient of variation of these productive time values, across two to three weeks worth of shifts. The resulting CV values will not be as high as the coefficient of variation of arrival times, or even of process times, because of the intrinsic capping of the productive time at 100% for each tool. If a tool is 50% productive on average, then it could possibly have standard deviation equal to average (or coefficient of variation of 1). For tools productive greater than 50% of total time, the standard deviation will always be less than the average, because the tool can never be productive more than 100% of the time. However, the CV of the productive time does give an indication of shift to shift variation in how the tools in the toolgroup are used. If the tools are always used to process wafers 70% of total time, then the CV of the productive time will be zero. Anything greater than zero indicates variation in either available time on the tools (e.g. we couldn't process wafers 70% of the time because the tool wasn't available 70% of the time for some shifts) or variation in arrivals to the tool (some days we had a lot of WIP to process, some days we didn't). For tools of the same utilization, a higher CV of productive time will most likely track with higher cycle times.

Coefficient of variation of scheduled and unscheduled downtime: The CV of the repair time for each tool is an indicator of places where downtime variability may be causing problems. Usually this is calculated separately for unscheduled downtime events vs. scheduled downtime events. The more consistent the repair times, the better for cycle time.

A20 and A80: Another way to capture availability variability, one that does not rely on coefficient of variation calculations, is to use the A20/A80 availability metrics. These metrics were described in detail in Issue 4.02. The way that you estimate them is to calculate the availability of each tool in a set of like tools for each day. Over a week or so, this should give you a series of different availability values, each representing the availability of one tool for one day. Sorting these in descending order, A20 is the availability value reached during the best 20% of the time periods. That is, 20% of the time, the availability is at that value or better. A80 is the minimum availability value reached during the best 80% of the time periods. That is, 80% of the time, the availability is equal to that value or better. The way that people use A20 and A80 is to graph them over time, and try to bring the A80 value up, so that it's closer to the A20 value. If these values are close to one another, it means that from day to day, and from tool to tool, the availability is consistent. Tools with widely dispersed A20 and A80 values are likely contributing arrival variability to downstream operations, and should be targeted for improvement programs.

Operator variability: For an indicator of where variability in operator availability may be causing cycle time problems, we recommend measuring the percentage of time that each tool spends in a "standby with WIP waiting" state. This is time that the tool is available, and has qualified WIP in front of it, but isn't processing wafers. This is usually an indication that there was no operator available to load the tool. It is possible to determine this data from the tool state transactions (indicating whether the tool is up or not) and the move transactions. It is not necessary to have the operator log the tool into some sort of "standby no operator" state (which would not be very accurate). "Standby with WIP waiting" time is often a hidden source of cycle time problems, especially where it occurs on tools that have a high utilization.

Step-level x-factors: Another way to start looking for variability problems is to record per-visit queue times and process times by tool-group, averaged across several days or a week. You can use the average total step cycle time, divided by the average recorded process time, as an indicator of step-level x-factor. Tools that have a high step-level x-factor are contributing more queue time than other tools. If these tools are not top bottlenecks, in a capacity sense, then the most likely explanation is that they are tools with a higher-than-average amount of variability. You will need to dig further into the data (for example, using the metrics described above) to determine the cause of the variability. Is it arrival variability? Is there a high variation in the process times of recipes run on this tool? Is the availability of the tool highly variable? Step-level x-factors don't report variability directly, but they are an excellent indicator of where to look, on a short-term basis, for variability problems.

Conclusions

Variability is one of the main sources of cycle time in wafer fabs. Variability affects the shape of the operating curve of cycle time vs. tool utilization. By reducing variability, we can move the knee of the operating curve for a fab, achieving a lower cycle time at the same throughput rate. Variability reduction is a relatively inexpensive way to improve cycle time, because it does not require the purchase of capital equipment, or any reduction in starts. However, in order to reduce variability in your fab, you need to be able to identify the specific sources of variability. In this article, we review some of the major sources of variability in fabs, and suggest several general methods for reducing fab variability. We then discuss in detail several metrics that you can use for quantifying and identifying specific variability problems in your fab. We believe that the first step to conquering a problem is understanding it in more detail.

We hope that this article will help you in tackling the problem of fab variability.

Closing Questions for FabTime Subscribers

What do you think are the biggest sources of variability in your fab? Do you have standard methods for quantifying arrival and process time variability, or tool uptime variability?

Acknowledgement

We would like to thank Tom Lambe of the ATDF (Advanced Technology Development Facility) at SEMATECH for discussions that contributed to this article.

Further Reading

■ P. Gaboury, "Equipment Process Time Variability: Cycle Time Impacts," *Future Fab International*, Issue 11.

■ 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).

■ J. Robinson and F. Chance, "The Three Fundamental Drives of Fab Cycle Time," *FabTime Newsletter,* Volume 6, No. 5, 2005.

■ J. Robinson and F. Chance, "Quantifying Availability Variability," *FabTime Newsletter*, Volume 4, No. 2, 2003.

■ J. Robinson and F. Chance, "Quantifying Wafer Fab Variability," *FabTime Newsletter*, Volume 4, No. 1, 2003.

■ 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.

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.shtml.

Subscriber List

Total number of subscribers: 2649, from 469 companies and universities. 23 consultants.

Top 21 subscribing companies:

- Maxim Integrated Products (195)
- Intel Corporation (155)
- Micron Technology, Inc. (88)
- ATMEL (74)
- Analog Devices (70)
- Freescale Semiconductor (64)
- Infineon Technologies (64)
- Cypress Semiconductor (58)
- International Rectifier (57)
- STMicroelectronics (57)
- Texas Instruments (56)
- X-FAB Inc. (54)
- NXP Semiconductors (50)
- Chartered Semiconductor Mfg (48)
- ON Semiconductor (48)
- TECH Semiconductor Singapore (48)
- IBM (37)
- Spansion (34)
- Seagate Technology (33)
- BAE Systems (29)
- Honeywell (29)

Top 3 subscribing universities:

- Virginia Tech (11)
- Ben Gurion Univ. of the Negev (7)
- Arizona State University (6)

New companies and universities this month:

- Ecole des Mines de Nantes
- Foothill Technology
- L&T Infotech
- University Science of Malaysia
- Wichita State University

Note: Inclusion in the subscriber profile for this newsletter indicates an interest, on the part of individual subscribers, in cycle time management. It does not imply any endorsement of FabTime or its products by any individual or his or her company.

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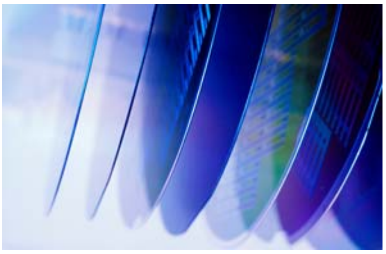
FabTime® Dispatching Module



Dispatch Configuration

Configuration projects are quoted on a fixed price basis for each site, and typically include:

- Dispatch rule and factor configuration.
- Training.
- Dispatch list feed to the MES (if applicable).

Dispatch Factors

- Batch code at the current tool.
- Lot priority.
- Downstream tool priority.
- Current tool FIFO.
- Current tool idle time.
- Downstream batch efficiency.
- Critical ratio.
- Earliest-due-date.
- Current step processing time.
- Remaining processing time.
- Current step qualified tool count
- WIP level at downstream tools.
- Up to five other site-specific factors.

Interested?

Contact FabTime for technical details.

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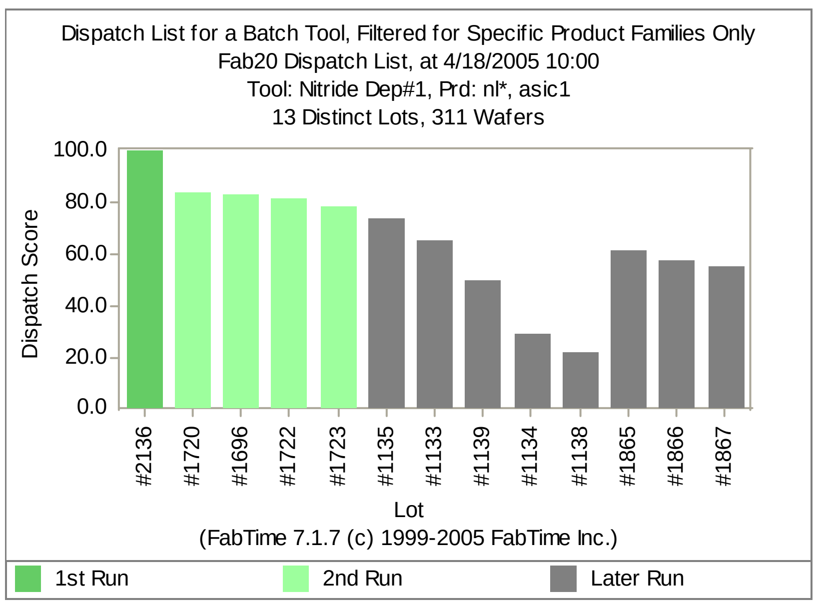
Web: www.FabTime.com

Do your operators make the best possible dispatching decisions?

- Do you struggle to balance lot priorities and due dates with tool utilization and moves goals?
- Do your critical bottleneck tools ever starve?
- Do you use standard dispatch rules, but feel that your fab's situation is more complex, requiring custom blended rules?
- Do you know how well your fab executes your dispatching?

FabTime's dispatching module is an add-on to our **web-based digital dashboard software**. At any point, for any tool in your fab, FabTime will show you the list of all lots qualified to run on that tool. This list will be ordered by the dispatching logic that your site has selected for that tool. This logic can use standard dispatch rules such as Priority-FIFO and Critical Ratio. However, you can also create custom dispatching logic using any combination of dispatch factors (shown to the left).

You can display dispatch lists in FabTime, and/or export them back to your MES. FabTime also includes a dispatch reservation system to hold downstream tools when a lot is started on an upstream tool, as well as dispatch performance reporting.



FabTime Dispatching Module Benefits

- Ensure that wafers needed by management are in fact the wafers that are run, while requiring less manual intervention on the part of management.
- Improve delivery to schedule, and the display of performance to schedule.
- Document the dispatching logic used by the best operators and make this available to all shifts.