FabTime Cycle Time Management Newsletter

Volume 19, No. 3 **July/August 2018**

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 development right now include support for fiscal calendars and display of hold percentage on WIP charts.

Editor: Jennifer Robinson

Keywords: Hot Lots; Data Models

Table of Contents

Welcome

Welcome to Volume 19, Number 3 of the FabTime cycle time management newsletter. We hope that people are having a wonderful summer. We have in our community news section an abstract from a recent conference regarding the development of a new set of semiconductor testbed datasets. Our software tip of the month is about tracking the percentage of hot lots in your fab using FabTime's Excel export functionality.

We have no subscriber discussion at this time. However, our main article was inspired by a subscriber asking if we had ever written about hot lots. We had done so, but not for more than a dozen years, and we felt that the topic was due for an update. We have extended our previous discussion about the impact of hot lots on cycle time, adding some recent research as well as new discussion regarding metrics and the impact of hot lots on fab capacity. We hope that you find this article useful.

Thanks for reading – Jennifer

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Community News/Announcements

Project to Create New Semiconductor Fab Testbed Datasets

While perusing abstracts from the most recent Modeling and Analysis for Semiconductor Manufacturing (MASM) conference (part of the Winter Simulation Conference), we were intrigued to note that Michael Hassoun (Ariel University) and Adar Kalir (Ben-Gurion University) are working on a new "testbed dataset" for simulating semiconductor fabs. This caught our eye because Jennifer and Frank were involved in the development of the long-used "MIMAC testbed datasets" and, in fact, our FabTime demonstration server uses an adapted set of data from that effort. Here's what Hassoun and Kalir's abstract says:

M. Hassoun and A. Kalir, "Towards a New Simulation Testbed for Semiconductor Manufacturing," *Proceedings of the 2017 Winter Simulation Conference*, 2017.

"We propose the creation of a new set of fab simulation testbeds. Extensions and additional features, not considered in the original MIMAC datasets, shall be incorporated in these new testbeds, thus allowing researchers to evaluate new methodologies with the same frame of reference. To do this, we surveyed the literature and mapped the pertinent research efforts of the past two decades. In this paper, we discuss in detail the various aspects of the new testbeds, in order to receive feedback from the simulation community on the importance of inclusion of some of the items in question; and the verification of the required inclusion of other items. Given the feedback, we aim to generate these testbeds within a year to serve as the new frame of reference for the benefit of the entire semiconductor manufacturing simulation community."

You can download the full paper from the INFORMS website.

FabTime welcomes the opportunity to publish community announcements, including conference notices and calls for papers. Send them to newsletter@FabTime.com.

FabTime User Tip of the Month

Track Your Percentage of Hot Lots Using FabTime and Excel Export

In our main article this month we discuss hot lots, including suggestions for the target percentage for hot lots in the fab. But just because your fab has a target for the number of hot lots doesn't mean that this target is being met over time. Sometimes lots are converted to hot in mid-flow. Sometimes hot lots may take longer to process than anticipated, resulting in extra hot lots in the line. Things happen.

FabTime does not directly have a chart that reports on percentage of hot lots, because "hot" isn't generally a yes-no flag applied to each lot. Rather, lots have assigned priority classes and there may be several priority classes corresponding to "hot." Calculating the percentage of the different types of hot lots thus requires a bit of extra effort, but it can certainly be

done. To view the trend in percentage of hot lots over time:

1. Generate the WIP Stacked Trend Chart. Set the Cross drop-down to "PriorityClass". Set the date range and period length of interest and press "Go." FabTime will display a WIP trend chart stacked by priority class.

2. Above the data table, click the link for "Excel (all rows)." Click to "Enable Editing," if needed.

3. Use formulas in Excel to calculate the percentage of hot lots. If you only have one hot lot priority class, you can just divide the "Wafers" column for that class by the "Total (wafers)" column. If you have multiple tiers of hot lots, you may need to first create an interim value that consists of the sum of hot lot priority classes. Fill down to perform the same calculations for all time periods.

4. Alternatively, if you wish to know the percentage of LOTS that are hot (e.g. if the hot lots have a smaller lot size), you first need to create a column that contains the sum of the "Lot" columns and divide into that instead.

5. Of course, you can graph the hot lot percentage over time in Excel, if you need to, as shown below.

We hope you find this tip useful. FabTime customers can subscribe to the separate Tip of the Month email list (with additional detail). Thanks!

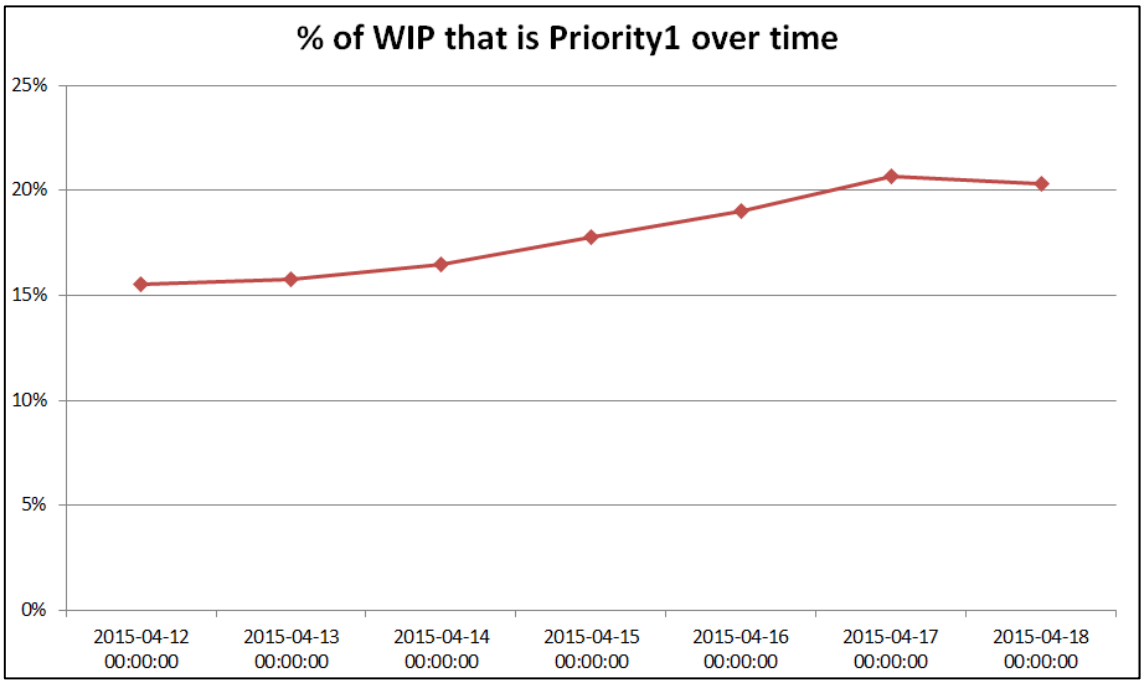

Figure 1. Example of percentage of Priority1 lots over time, generated from FabTime data exported to Excel

Subscriber Discussion Forum

FabTime welcomes the opportunity to publish subscriber discussion questions and responses. Simply send your contributions to Jennifer.Robinson@FabTime.com. We have no subscriber discussion at this time, though our main article was inspired by a question from a subscriber.

Cycle Time and Hot Lots: Updated

Introduction

A subscriber wrote to us recently to ask if we had written about the impact of priority lots on overall fab performance, capacity, and cycle time. He also wondered if we had any recommendations for percent values of different types of hot lots in the fab. We had written about hot lots back in issues 3.02 and 6.08, but as these issues were published more than a dozen years ago, we thought that it was worth publishing an update.

In this article we discuss reasons for hot lots, the two primary types of hot lots, and the impact of hot lots on cycle time and fab capacity. We also make recommendations regarding hot lot management, including dispatching. We then share a few thoughts on metrics for tracking hot lots. Finally, we include several references regarding hot lots. We welcome your feedback on this topic.

Background: Type of Hot Lots

Every wafer fab that we visit has hot lots. There are many reasons for these hot lots:

- Lots for certain customers may be run at a higher priority than lots for other customers.
- Lots made to order may be run at a higher priority than lots made to stock.
- Research and development lots are often expedited relative to regular production WIP.
- First silicon for new products is frequently given highest priority.
- A yield bust or downstream yield improvement can lead to re-prioritization of a portion of the WIP.
- Lots late in their process flow are sometimes expedited to meet weekly delivery goals.
- Short-term priority changes are sometimes made to fill WIP holes at critical tools or otherwise manage product mix issues.
- Lots that are outliers in terms of cycle time are sometimes re-prioritized, particularly those that are behind schedule.
- Etc...

While very large fabs may be able to set aside dedicated tools for hot lots, in our experience this is rare. Hot lots are generally processed on the same equipment used for regular lots and, thus, compete with (and degrade the performance of) regular lots.

Although there are many types of hot lots, we can classify them into two primary categories in terms of how they are processed: front of the line hot lots and hand carry lots.

"Front of the line" hot lots (also called "regular hot lots") are lots that are given a higher priority than others for dispatching. These lots are non-preemptive and do not require breaking setups or holding tools idle. They are sometimes stored in different-colored lot boxes to make them easier to identify. There may be multiple sub-classes of front of the line hot lots (e.g. priority 0080, 0085, 0090, etc.).

"Hand carry" lots are the highest priority of hot lots. They may be preemptive and require operators to break setups. Often tools are held idle in advance of these lots so that the hand carry lots never have to wait. Hand carry lots are generally very limited in quantity. Often a single person (per shift) is responsible for each hand carry lot as it moves through the fab.

We have heard many alternative names for hand carry lots over the past several years and share some of them with you here: Zero-Queue Lots, Ambulance Lots, Racetrack Lots, Screamer Lots, Lightning Lots, Platinum Lots, Priority1 Lots, Nuclear Lots, Rocket Lots, Turbo Lots, Mickey Mouse Lots, and CEO Lots. We

particularly like "Ambulance Lots" because of the clear image of everything else getting out of the way as the lot moves through the fab.

In practice, of course, there can be some blurring between these two categories, but we think that they are useful for the purposes of discussion. In a later section we briefly discuss a policy that does involve holding tools idle for regular hot lots.

Impact of Hot Lots on Regular Lot Cycle Time

As discussed above, there are many good reasons to have hot lots in a fab. However, hot lots are not free. They increase variability in the fab, which drives up cycle time. They also frequently require special handling of some sort, which takes operators away from other things and, hence, drives up cycle time. Hand carry lots are particularly disruptive. Whenever a tool is held idle for a hot lot, capacity is lost on that tool. Whenever a setup is broken, or an additional setup is required for a hot lot, capacity is lost. Whenever a batch tool is run nearly empty because of a hot lot, capacity is lost. And, as readers of this newsletter well know, any capacity loss on a tool decreases the buffer of standby time for the tool, and drives up cycle time.

Front of the Line Hot Lots:

Theoretically, this is less of a problem when dealing with front of the line hot lots. If tools are not held idle, and the lot priority is merely used to help decide which lot to process next, then all front of the line hot lots do is move queue time from one class of lots to another. That is, queue time is moved from the high priority lots (which go directly to the front of the queue) and added to the regular lots (which incur extra waiting time while the hot lots are processed). Issue 3.02 included a formula for estimating this impact. Briefly recapping here, our standard formula for estimating cycle time x-factor for a single tool is:

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

When we have front of the line hot lots, the cycle time of the regular lots is inflated by a multiplier, and we have:

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

Where:

- **Hot Lot Multiplier = [1 / (1 – Hot Lot Utilization)]**.

Hot Lot Utilization is simply what the tool utilization would be if only hot lots were present, and represents the capacity that the hot lots take away from the regular lots. It can be calculated by taking the overall tool utilization and multiplying by the percentage of hot lots. For example, if we have a tool with 85% overall utilization and 10% hot lots, then the Hot Lot Utilization is 8.5%. The Hot Lot Multiplier in this case is [1 / (1 – .085)] = 1/0.915 ~= 1.09. That is, if we have 10% hot lots at 85% tool utilization, then the cycle time of the regular lots is inflated by approximately 9%.

Note, however, that if we add additional hot lots, the cycle time increases non-linearly. In the above example, if we have 25% hot lots, then the Hot Lot Utilization is 21.2% and the Hot Lot Multiplier is [1 / (1 – 0.21.2)] = 1/0.788 ~= 1.27. That is, with 25% hot lots, the cycle time of the regular lots is inflated by approximately 27%. A graph displaying regular lot and hot lot cycle times for a tool with different percentages of hot lots is shown at the top of the next page.

Although this example is for a one of a kind tool, in our operating curve spreadsheet (a tool used in our training class) we use the same Hot Lot Multiplier to estimate the impact of hot lots on regular lot cycle time for tool groups with multiple tools. This is because the impact of front of the line hot lots stems from the capacity that they take away from the

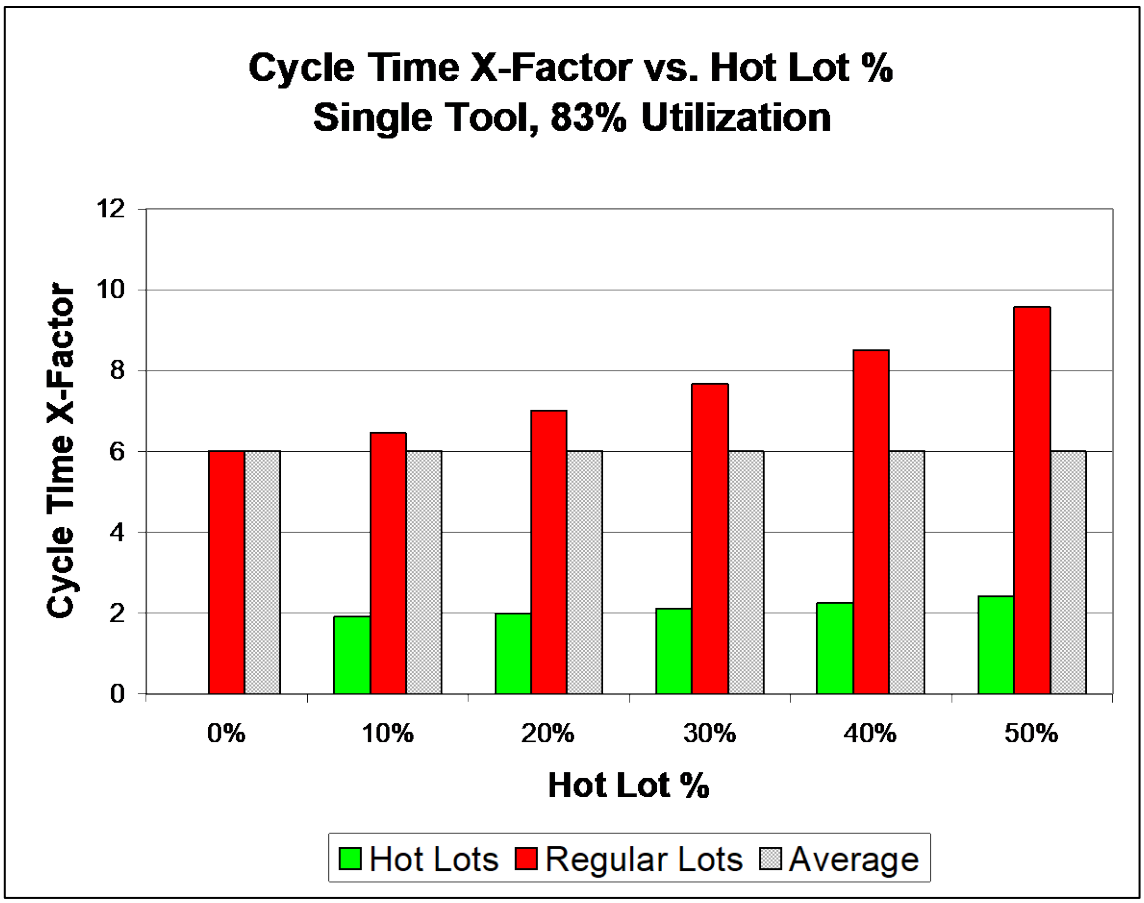

Figure 2. Impact of hot lots on regular lot cycle time, by percentage of hot lots

regular lots, and this effect will spread out across the different tools in the tool group.

The above formula for the Hot Lot Multiplier is a lower bound on the real-world impact of front of the line hot lots, of course. That formula assumes that no additional queue time is created - merely that queue time is moved from the hot lots and spread out over the higher volume of regular lots. The overall average queue time across all lots remains unchanged.

In reality, hot lots increase the overall average cycle time in the fab due to their impact on variability and tool capacity. This is true even for front of the line hot lots, if they lead to additional setups, smaller batches, or the occasional wait for an arriving lot.

Hand Carry Lots:

The exact magnitude of the effect of hand carry lots is difficult to quantify, even using simulation models, because so much is influenced by individual operator decisions (how long to hold a tool idle for a hot lot, for instance, and how far to look ahead for one that is coming). The magnitude of the impact also depends on how heavily utilized the tools in the fab are to begin with. For tools that have excess capacity, holding the tool idle to wait for a hot lot is not likely to have a big effect. However, holding a very heavily utilized tool idle for an upcoming hot lot can lead to lost capacity that can never be recovered.

What we do know about the effect of hand carry lots on cycle time is that the more hand carry lots there are the worse the effect. If there are more than one or two true hand carry lots in the fab at a time, they will start to interfere with one another, defeating the goal of no waiting for each lot. In abundance, hand carry lots may also be subject to a "boy who cried

wolf' effect, in which people start to take them less seriously. Their cycle times will start to creep up in that instance.

Impact of Hot Lots on Capacity

As already mentioned, hot lots, particularly hand carry lots, can result in lost capacity on tools. This drives up the cycle time of regular lots, of course, and it can also, in extreme cases, reduce the overall throughput of the fab. If you lose capacity on heavily loaded bottlenecks, whether due to holding the tool idle or running extra setups, you may not be able to recover that capacity at all.

As mentioned above, it may be possible for larger fabs to do some tool dedication to preserve capacity for hot lots. However, this will tend to lead to less balanced use of capacity (some tools at a higher loading and others at a lower loading), as well as smaller tool groups. Both of these are associated with increased cycle time.

Recommendations for Managing Hot Lots

Front of the Line Hot Lots:

It is our recommendation, based on talking with people in fabs, and on the formula discussed above, that most fabs try to keep front of the line hot lots to 5-10% of total WIP. An exception would be fabs in which there are truly separate classes of lots, as a fab that makes some WIP to order and other WIP to stock. In the latter case, it might make sense to always prioritize the make to order WIP ahead of the make to stock WIP, and generally accept higher cycle times for the make to stock WIP. But in general, it's best to keep hot lots to a minimum.

Our earlier recommendation on this was to simply keep below 10%, but we have seen fabs scale this back over the years, as their understanding of variability has improved. It's now our observation that 5% is a common target.

For a quantitative basis to this 5% threshold, remember our Hot Lot Multiplier above. If we have a tool with 85% overall utilization and 5% hot lots, then the Hot Lot Utilization is 4.25%. The Hot Lot Multiplier in this case is [1 / (1 – .0425)] = 1/0.9575 ~= 1.044, which is less than the percentage of hot lots. [Bearing in mind that this is a lower bound on the impact.] As the percent of hot lots increases, however, the cycle time penalty for regular lots increased non-linearly. Also, above 5-10%, hot lots are more likely to interfere with one another and, hence, the hot lot cycle times will be higher. In general, the fewer hot lots there are, the better their cycle time will be.

The other general recommendation that we have regarding front of the line hot lots is to keep things as simple as possible. Any time you change lot priorities on the fly, or have some special class of hot lots that changes every few days, you are introducing variability into the fab. You are also making dispatching more complex, and potentially increasing queue time as operators search the queue for the right hot lot. The best solution for overall cycle time is always the lowest variability solution. It is far better to reduce the overall average cycle time across the entire fab than to struggle to manage ten different, ever-shifting classes of priority lots.

Hand Carry Lots:

For hand carry lots, we recommend no more than one or two lots in the fab at one time. This is partly because these types of hot lots are very disruptive to the fab, and to the cycle time of other lots, such that they should be used sparingly. Also, as mentioned above, in larger quantities the hand carry lots will interfere with one another, defeating their own purpose. Even in small quantities, if the hand carry lots are run too frequently, it will be difficult to get people to continue taking them seriously.

We worked with one of our customers on a procedure for super-expediting hand carry lots in a large wafer fab (see the Hillis

and Robinson paper referenced below). This procedure involved setting a goal for the maximum hand carry lot queue time, setting a goal for the maximum number of hand carry lots in the fab, and establishing key resource buy-in for hand carry lots. The site used FabTime's software as part of an automated tracking and alerting system and developed tactical communications plans regarding the hand carry lots. The customer applied this procedure to the first lot of a critical new product. This lot went from being 14 days behind schedule to shipping early (as described in the referenced paper). The conclusions regarding hand carry lots that came out of that study were:

- Production management buy-in is essential, because super-expedited lots are very disruptive to production and will generate resentment unless their purpose is clearly understood. (That is, prevent the "boy who cried wolf" effect as much as possible.)
- Getting access to up-to-date information about fab performance is critical to success.
- Communication is the ultimate key to success.

Use of a Hybrid Reservation-Based System:

We did read an interesting recent paper proposing the use of a reservation-based system for reserving hot lot capacity on tools while attempting to minimize the impact on the cycle time of the regular lots. [See Chung et. al. below, with link to the full paper.] This seems to be a bit of a hybrid relative to our classification in that all hot lots are considered, but tools are held idle to wait for hot lots via the reservation system.

The approach requires the estimation of earliest expected arrival times for the hot lots. In order to minimize capacity loss on tools while waiting for hot lot reservations, the authors introduce a concept of reservation depth to control the influence of the reservation. The reservation depth is basically how many steps back you are willing to look for hot lots - the further you look, the more weight you are putting on the on time delivery of the hot lots. The authors propose an algorithm that looks at reservation depth and different choices of tool within a tool group to balance waiting time for the high priority lots against capacity loss on the tools.

The authors tested the results [using the MIMAC testbed datasets described in the community news section above] using simulation, in particular looking at reservation depth and at the differences between 10% and 20% hot lots in the fab. They found generally positive results compared to other reservation systems in terms of minimizing impact on the regular lots. It's beyond our scope to go into the details here, but we do recommend that those who are interested check out the paper. There's also a more extensive literature review than we have included here.

Metrics and Tools for Managing Hot Lots

There are a variety of tools and metrics that can be used for monitoring hot lots. Hot lot-related reports in (or derivable from) FabTime include:

- List of hot lots in queue and how long each has been waiting at the current operation, as shown at the top of the next page in Figure 3.
- Percentage of regular hot lots, as shown previously in Figure 1.
- Detailed lot history for individual hot lots showing how long the lot waited at different steps. This can be used as learning to prevent similar problems for future lots.
- Lot progress chart (or list across lots) indicating expected shipment dates for high priority lots relative to due dates. This can be used to identify hot lots at risk of being late.

FabTime's software also includes the capability of setting alerts for things like:

- A certain lot has been waiting in queue for more than some target (e.g. for hand carry lots).
- A certain lot has arrived at a particular operation (e.g. if an engineer needs to be notified, again for hand carry lots).
- Any lot of a certain priority class has been waiting in queue, or has been in process, or has been on hold, for more than some target. This can be used for front of the line hot lots to be sure that they are generally on target.

Conclusions

Hot lots have remained a fact of life for wafer fabs for the 25 years that we have been involved in the industry. There are many reasons why people have hot lots, and there is no question that hot lots help in certain circumstances. For example, achieving great cycle times for first silicon lots can be a mission-critical undertaking affecting the overall success of a company. However, there is also no question that hot lots increase the cycle time of other lots.

The cycle time impact on regular lots from front of the line hot lots can be approximately quantified and increases non-linearly with percentage of hot lots.

The cycle time impact on regular lots from hand carry lots can be much greater, due to both increased variability and to lost capacity from held tools, setups, etc. To minimize the impact on regular lots, and to maximize the chance that hot lots achieve their target cycle times, we recommend that fabs carry no more than 5-10% of their WIP as front of the line hot lots, with no more than one or two hand carry lots at one time. Fewer hot lots would be even better, and might leave manufacturing personnel with some additional time for overall cycle time improvement efforts.

Closing Questions for FabTime Subscribers

Are there other reasons for hot lots that we're missing? Are these recommendations consistent with what you're seeing in your fab? What metrics do you use for managing hot lots in your fab? Have you tried a reservation-based system for improving cycle time of regular hot lots?

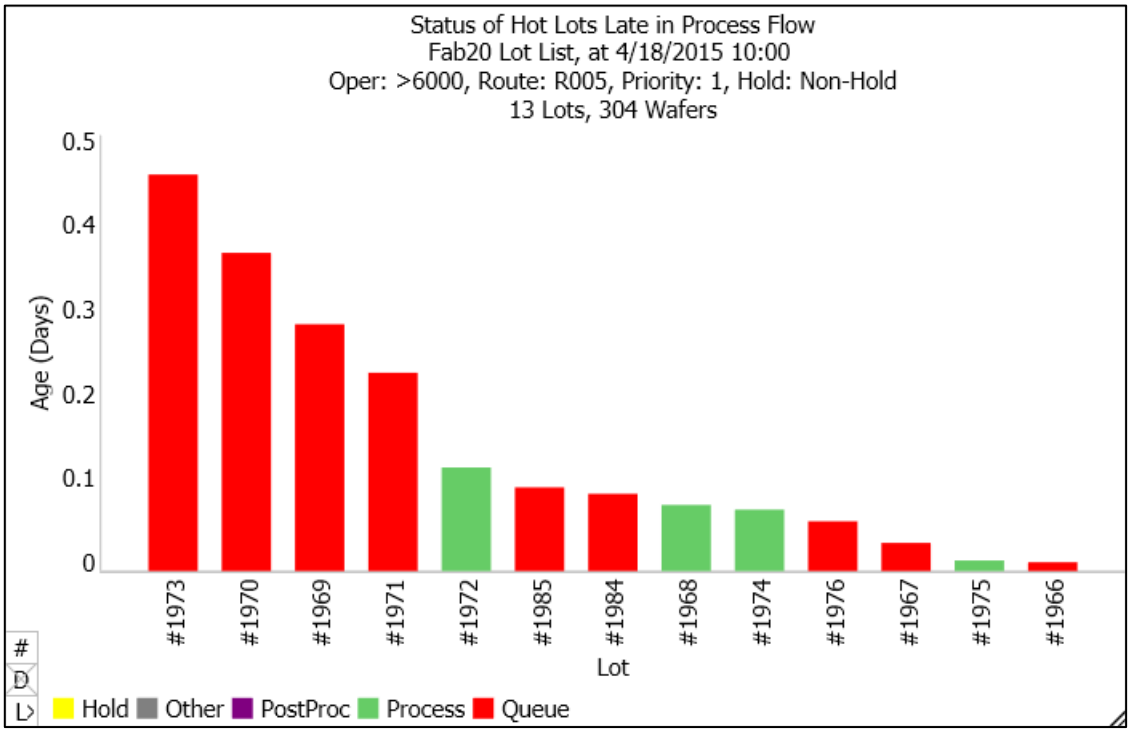

Figure 3. FabTime chart showing status of hot lots late in the process flow

Acknowledgement

Special thanks to Mike Hillis for his contributions regarding the super-expediting of hand carry lots.

Further Reading

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Subscriber List

Total number of subscribers: 2762

Top 20 subscribing companies:

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- Infineon Technologies (144)
- Micron Technology, Inc. (137)
- Intel Corporation (113)
- GLOBALFOUNDRIES (108)
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- Zymergen (35)
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- Virginia Tech (7)

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- BH Electronics (1)
- bTendo (1)
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- DeHart Consulting, Inc. (1)
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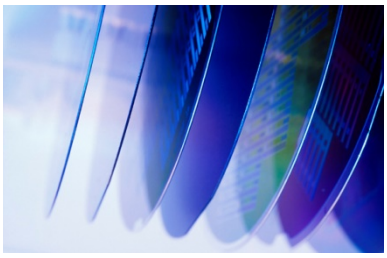
FabTime® Dispatching Module



Dispatch Configuration and Support

We offer our dispatching module for a single, fixed monthly fee (on top of your regular FabTime subscription). This includes:

- Dispatch rule configuration via user-friendly web-based interface for standard factors
- Training.
- Dispatch list feed to the MES (if applicable).
- Support and upgrades.

Custom dispatch rules and consulting from our dispatching expert available for additional fee

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 or staging time at downstream tools.

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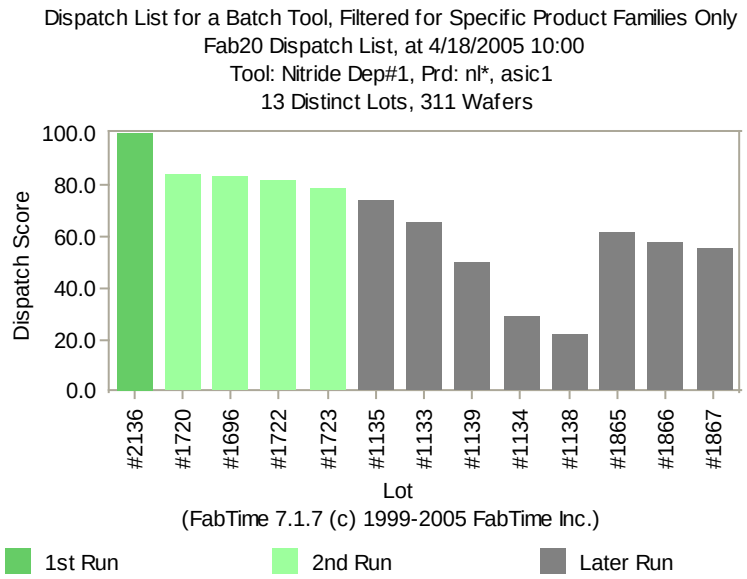
Contact FabTime for details.

FabTime Inc.
Phone: +1 (408) 549-9932
Fax: +1 (408) 549-9941
Email: Sales@FabTime.com
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 dispatch strategy?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 now (as of 2016) also includes an optional **short-interval scheduler**.



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.