FabTime Newsletter

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Information

Publisher: FabTime Inc. FabTime sells cycle time management software for wafer fab managers. FabTime's mission is to help the people who run fabs improve performance by: 1) letting them configure their own charts, so that they don't need assistance from IT for each new data request; and 2) including them in a community of people around the world working to improve fab operations.

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Keywords: Bottlenecks; Tool Availability; Dispatching

Table of Contents

Welcome

Welcome to Volume 21, Number 4 of the FabTime Cycle Time Management Newsletter. We hope this issue finds you and your family all safe and well and managing in this COVID-changed time. In this issue we have an announcement about our upcoming software release and a few tidbits of potential interest to the newsletter community. In our subscriber discussion forum, we have a request for information sharing related to the state of the art in planning, scheduling, and dispatch, and another regarding the potential elimination of lead wafers in photo. We also have a suggestion regarding the column format for the PDF newsletter. You'll see in today's issue, for PDF subscribers, that we're experimenting with a single-column format for improved mobile-friendliness.

Foreshadowing our main article, this issue's software tip of the month is about using tab filters to track short-term bottlenecks. The main article was written in response to a subscriber question about how to identify those tools likely to be a problem over the coming shift or day. We define short-term bottlenecks and discuss using the new WIP Hours metric to identify them. Following a detailed example illustrating the use of WIP Hours and tool status information, we close with a discussion of other metrics likely to tease out short-term bottlenecks from the vast array of fab metrics. We hope you find this useful and welcome discussion of other approaches for tracking short-term bottlenecks.

Thanks for reading! – Jennifer, Frank, Lara, and the FabTime Team

Community News/Announcements

Patch 113 Released for Early Adopter Site Production Use

We're still putting the finishing touches on Patch 113 of FabTime's software. However, a couple of the new features are in such high demand that we have released an early version for production use to those sites ready to test drive the new features. Highlights of this version include:

- Integration of a third-party engine for displaying and manipulating data tables (ag-Grid: https://www.ag-grid.com/).
- Enhanced PowerPoint integration (embed FabTime charts in PowerPoint presentations, mix images with other content, and automatically refresh FabTime images).
- JMP/Excel/PowerQuery integration (Pull FabTime data into Excel dashboards and merge FabTime and non FabTime data for analysis via JSON format).
- New Tool SubState Visit List chart (e.g. filter for SubState=WaitForTech to see all visits that had any WaitForTech time).
- New Tool Scheduled PM List for displaying future PMs.
- A formatting revamp for Help pages / improved mobile-friendliness.

A Few Highlights from Jennifer's LinkedIn

Jennifer continues to share articles about business management, the semiconductor industry, and productivity improvement on her LinkedIn feed. Recent posts of relevance here have included:

- A call from the CalPoly Industrial & Manufacturing Engineering (IME) Department's Systems Optimization Club for project sponsors for next year. "Would your business or division benefit from a team of Cal Poly engineers working for free? Well, you're in luck because students are eager for project experience and the Systems Optimization Club (Cal Poly) is looking for next year's project sponsors. All you have to do is fill out this interest form and the club officers will contact you and get the ball rolling: https://bit.ly/2ZrXBUV."
- A WSJ article about the newly announced acquisition of Maxim Integrated by Analog Devices. As noted in the article: "Both Maxim and Analog are major players in analog semiconductors, used in areas such as power management for automotive batteries. A combination of the two would create a more muscular competitor to Texas Instruments Inc., the leader in analog semiconductors with a $119 billion market value. Analog would also gain access to Maxim's army of hardware engineers." We'll also note here that both Maxim and Analog Devices have hosted multiple sessions of FabTime's cycle time management course in the past, one more indication of a level of compatibility between the two companies.
- A WSJ article about possible spending by the US to bolster the semiconductor industry. "A (bipartisan) campaign to expand semiconductor manufacturing in the U.S. gained traction Wednesday with the introduction of legislation to allocate tens of billions of federal dollars to domestic chip-making and research programs."

For more industry news, connect with Jennifer on LinkedIn:
http://www.linkedin.com/in/jenniferrobinsonfabtime

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

FabTime User Tip of the Month

Use Tab Filters to Track Short-Term Bottlenecks

In the newsletter's main article this month (see below), we propose using WIP Hours by Tool to identify potential short-term bottlenecks in a fab and investigating further by looking at each tool's current status. By definition, the list of short-term bottlenecks will vary by day. In today's tip, we suggest using tab filters to track the changing list of short-term bottlenecks. Here's how:

1. Generate your list of candidate tools for today's short-term bottlenecks list. One idea might be to generate the Tool Qualification WIP Detail chart and look in the data table for tools that have a high level of WIP at operations for which only one or two tools are qualified (see the main article below for other ideas).
2. Generate the Tool WIP and State List chart. You do not need to include any tool filters, because that will be done using Tab Filters.
3. Add the chart to a new home page tab (e.g. "Short-Term Bottlenecks").
4. On the new home page tab, check the box to "Set Tab Filters". Select "Tool" from the list and click the "Add" button.
5. In the Tool: field, manually enter the names of the tools in your candidate short-term bottlenecks list, separated by commas. Once you start to enter each name, FabTime will auto-populate and allow you to select each name.
6. Press the "Go" button. FabTime will populate the Tool WIP and State List chart using the set of short-term bottlenecks.
7. Add other charts to the page as needed. For example, add the Moves Pareto by Tool to watch the moves for the short-term bottlenecks list over the shift.
8. As your short-term bottlenecks list changes over time, you can manually update the set of tools in the "Tool" tab filter. You'll then see the tool status data for the current list. While this manual updating is a bit cumbersome, this approach allows you the flexibility to include short-term bottlenecks that you identify from a variety of different sources. You can also maintain comma-separated lists of short-term bottlenecks in a text file and copy and paste those into the Tool tab filter as needed.

We hope that you find this tip useful. If you are using Patch 113 and would like instructions for using the WIP Hours chart to identify short-term bottlenecks, just reach out to Jennifer.Robinson@FabTime.com.

Subscribe to the separate Tip of the Month email list (with additional discussion for customers only) here: http://www.fabtime.com/tip-of-the-month.php (note new link). Thanks!

Subscriber Discussion Forum

State of the Art in Scheduling, Dispatching, and Planning for Wafer Fabs

Peter Gaboury from STMicroelectronics wrote: "Our fab is currently defining our vision for lot dispatching, planning and scheduling for the upcoming years, focusing on the shop floor (operators) point of view.

Today, lot and reticle handing in the photolithography area are done by AMHS (a hybrid overhead & collaborative robot solution), and in the remaining areas, lot loading is done manually by operators. Overall, we use RTD for dispatching, with some custom rules, displaying the dispatch details on a web-based tool. In the photo area, the operators are planning lots using a planner software application, where

the WIP for the equipment is displayed. Operators are preparing the plan using a "drag and drop" software tool. The plan constructed by the operators is then entered into a tool task list, and when a load port is finished, or when a load port is available, the AMHS system executes the tool task list. On average, in photo, we are planning WIP on each piece of equipment for the next 3 – 4 hours. We have 2 to 2.5 hours of WIP on the ceiling in overhead buffers.

We are interested in understanding what is the current state of the art in the industry for scheduling, planning and dispatching, particularly in how, and who, is planning lots on the tools."

FabTime Response: We would be happy to aggregate feedback from other subscribers on this topic (anonymizing responses as requested). Depending on the amount of input that we receive from the subscriber community, we will write a follow-up article on this topic for a future newsletter.

Lead Wafers in Photo

Jimmie Darrington from Microchip wrote: "I have a question concerning lead wafers in photo, and I wondered if this subject had ever been studied by FabTime. Let me explain what I mean.

In our internal fab, we have a policy for ensuring correct Critical Dimension and overlay adjustments on photo layers. If too much time has passed (several months) between the processing of a specific device and layer on a lithography stepper, a single wafer is split from the lot and processed through coat, expose, and develop. An expert adjusts the stepper exposure and other process parameters manually based on calculations from the stepper and empirical data. The single wafer is referred to as a lead wafer. The lead wafer is then measured to ensure all metrology measurements are passing. If so, the rest of the wafers in the original lot is sent on using the data from the lead wafer. If not, the lead wafer is reworked through strip and sent through again.

One idea we have considered is to eliminate the lead wafer and simply commit the entire lot, reworking the lot if post-exposure measurements do not pass. We have found that many of our layers and devices have good adjustment data and pass on the first try the vast majority of the time. The thinking is to save time and effort on the lead wafer.

Have you all ever discussed this? For those who made this change, we would be very interested to know how the elimination of photo lead wafers was justified in other factories. What metrics were tracked? How much effort was put into calculating production value changes? What happened to full-lot rework rates? Did they increase, decrease, or stay about the same?"

FabTime Response: Our take on this is that you would probably be better off eliminating the lead wafers and just committing the entire lot. You're adding variability by sending that single wafer, and that variability likely outweighs any savings that you get from occasionally avoiding the reworking of an entire lot. But it is likely that other subscribers have had experience with this, and we would be happy to find out for you. Does anyone have thoughts to share on this?

Single Column for PDF Newsletter

Aubrey Howe from Skyworks pointed out that the two-column format that we've been using for the PDF version of the newsletter is not mobile-friendly. He suggested that we do a trial single column issue for this month and see if people like it better. As it turns out, we like the new format better already. If you disagree, please do let us know. If you are reading the HTML email version and would like to switch to or add the PDF version, just reply to let us know that, too. Incidentally Aubrey, who has an excellent memory, remembered that another subscriber had suggested this back in 2010. We raised the question in Issue 11.04. No one responded, so we didn't make the change. It seems like past time to do so.

FabTime welcomes the opportunity to publish subscriber discussion questions and responses. Simply send your contributions to Jennifer.Robinson@FabTime.com.

Identifying Short-Term Bottlenecks

A subscriber wrote earlier this year to ask:

> "Have you ever done an article on identifying priority tool sets for the day / shifts? Something along the same lines of cycle time bottlenecks in your last article (Issue 21.01), but more tactical. E.g. What tools do I need to make sure run at their best over the next 24 hours?
>
> I have some done work on this topic by looking at WIP levels and priorities, tool availability history and current status and activity levels (e.g. moves) vs. targets, but I'd like to know if you have any related articles, or propose it as a new topic for your newsletter."

While we've written in the past about various metrics that can help to answer this question, we thought that focusing on this topic would make a useful companion piece to the cycle time bottlenecks article.

We start by defining short-term bottlenecks. We then propose using the metric WIP Hours, together with equipment status, to identify top candidates. We follow up with a discussion of other metrics that highlight current or near-term problem tools.

Short-Term Bottlenecks

Fabs are complex places. We're not sure that any one chart can answer the question of "what tools should I focus on over the next 24 hours?" However, we do think that a good place to begin is by generating a list of short-term bottlenecks based on current tool status and WIP levels.

We define a short-term bottleneck as a tool or tool group for which, over the next 12-24 hours, required capacity is likely to exceed available capacity. Here "is likely" will depend on the tool's future availability, which we can't know for certain. But in the interest of not letting perfect be the enemy of good, we can still identify tools that appear at risk based on the information that we do have.

In the long run, fabs don't typically plan for required capacity to exceed available capacity. However, in the short run WIP bubbles can occur and availability can fluctuate. This variability causes short-term bottlenecks. Short-term bottlenecks often coincide with long-term, planned bottlenecks (the tools that are loaded most heavily under the current capacity plan). But any tool can become a short-term bottleneck in the highly variable environment of a fab. This is especially true for one-of-a-kind and two-of-a-kind tools.

Traditionally, short-term bottlenecks have been identified by walking around the fab and looking for piles of WIP. Wherever WIP is piling up, that's a short-term bottleneck. This method works reasonably well in many cases but is less successful when WIP is stored in central locations (e.g. stockers), or when process times are highly variable (either extra-long or extra-short). It's also difficult when using this method to account for distinctions like lot priority.

Years ago, we started seeing fabs look also at inventory age, which is the time that each lot has been waiting at its current operation. Looking at tools that have a high cumulative inventory age for lots in queue tends to help find problems. This approach tells you where you have WIP that's been waiting a long time, though there's less information about why that is, or how long that WIP will take to process.

A metric that we wrote about last year, WIP Hours, can be used to focus better on the tools that don't have enough capacity to process the WIP that's waiting. WIP hours is the estimated hours of required processing time for WIP in queue at a tool.

WIP Hours

We wrote back in Issue 20.03 about computational issues and open questions around WIP Hours. Since then, we have worked with our User Group to define and implement this metric. We believe that a good

first step in identifying short-term bottlenecks in a fab is to use WIP Hours (or Effective WIP Hours, discussed below).

WIP Hours are computed by estimating the process time for each waiting lot, dividing process time among qualified tools, and summing by tool. For example, if we have the following UPH (or WPH) at the following Etch ToolGroup:

- Etch01: 25 wafers per hour
- Etch02: 25 wafers per hour

And we have the following Lots in queue and qualified to run on Etch01 and Etch02:

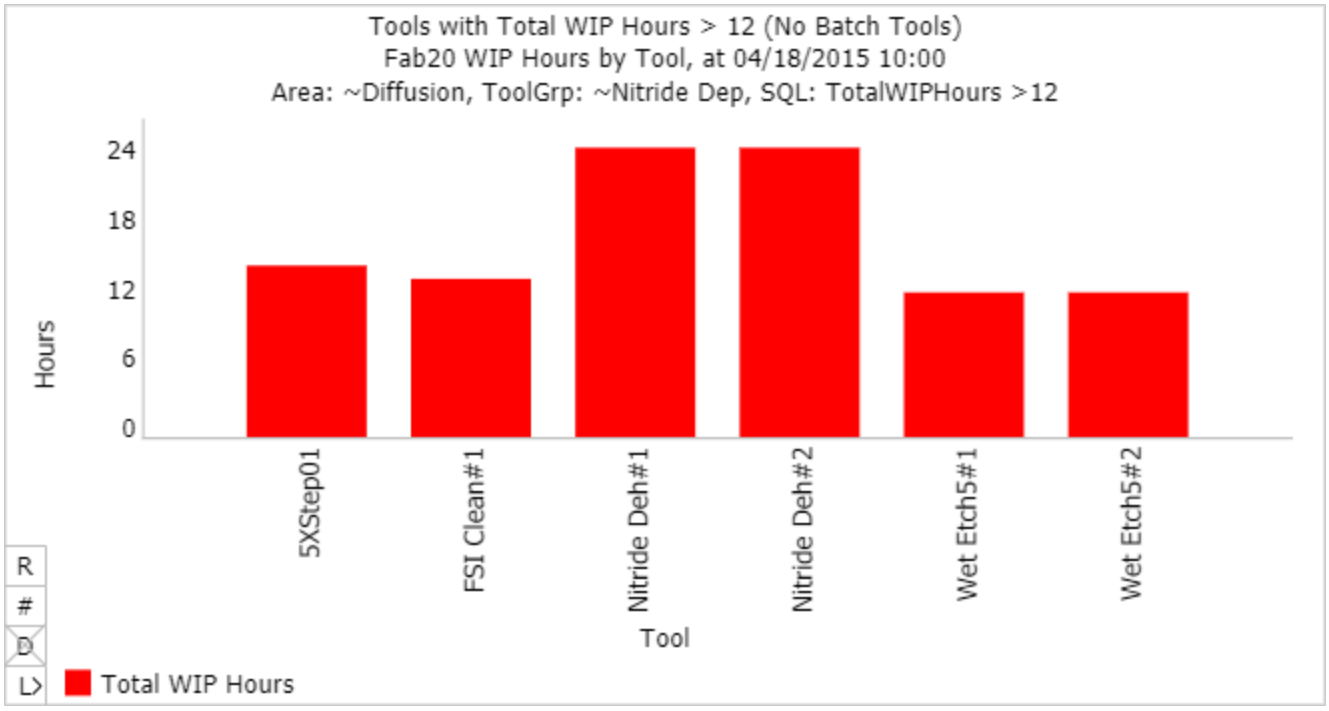
- Lot1: 25 wafers
- Lot2: 25 wafers

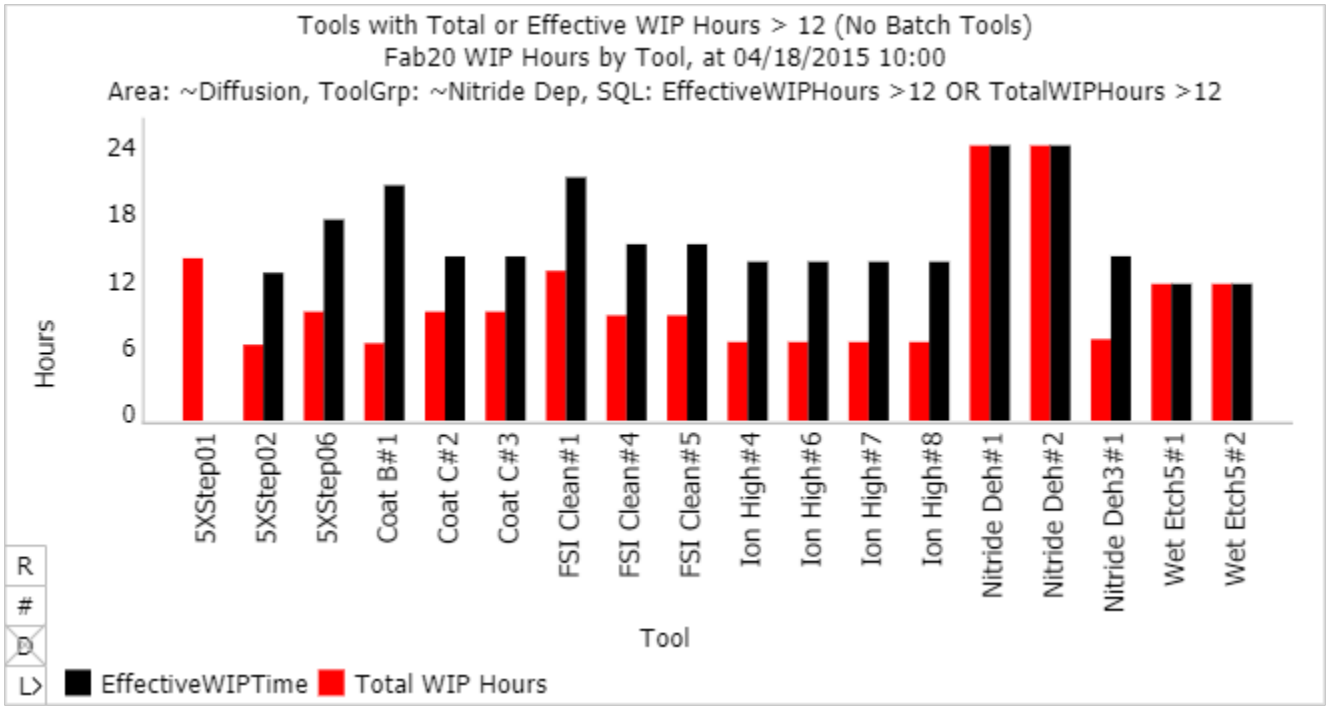
Each tool has 1 WIP Hour (its 0.5-hour share of process time for L1, plus its 0.5-hour share of process time for L2), and the Etch ToolGroup has 2 WIP Hours of process time in queue.

WIP Hours as a metric provides information about the WIP that one might see in queue in front of tools. For example, if there is a large quantity of WIP in front of a tool, but the WIP Hours = 4, then the tool will likely be able to process the WIP within the shift. However, if the WIP Hours = 85, this is likely a short-term bottleneck as the WIP could take 3 or more days to clear. WIP Hours is helpful in identifying bottlenecks by presenting locations where productive capacity is limited, since WIP levels alone can be misleading without knowing tool capacity.

WIP Hours calculations divide process time among qualified tools. If one or more qualified tools are down, this can undervalue the actual effective WIP Hours at a tool. FabTime calculates Effective WIP Hours the same way as standard WIP Hours, but instead divides process time among qualified tools that are available to process.

We can get an indication of short-term bottlenecks by looking at WIP Hours by Tool and filtering for all tools for which WIP Hours is greater than 12 hours. This gives us the set of tools that have more WIP in queue than can be processed during the coming shift. Of course, this bar can be set higher or lower depending on the situation in each fab. Here's an example from our demo server:





There are six tools (after some exclusions due to issues specific to our demo server) for which the hours of WIP waiting to be processed exceeds 12. For two of these tools (which are in the same tool group), the hours of WIP to be processed exceeds 24 per tool. This means that if the tools were run continually, with no downtime, it would still take 24 hours to clear the current WIP from the tools. These tools (Nitride Deh#1 and Nitride Deh#2) clearly qualify as short-term bottlenecks and require further attention.

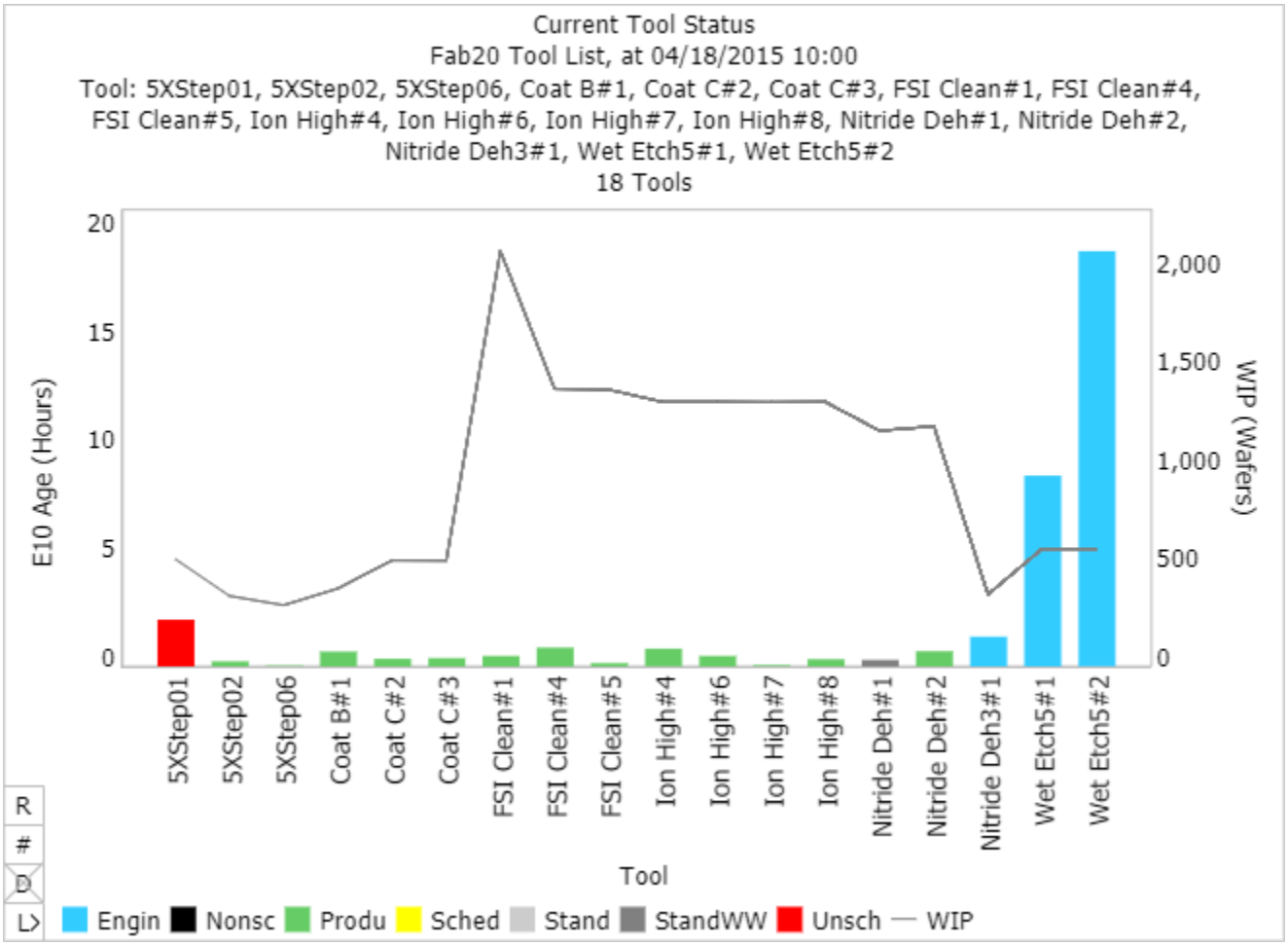
We can go a step further by also looking at tools with high Effective WIP Hours. This takes tools that are currently down into account. A note of caution is in order, however. When calculating Effective WIP Hours per Tool when the number of effective tools is zero, FabTime sets Effective WIP Hours to zero. This is to avoid dividing by zero. Thus, exclusively using Effective WIP Hours per Tool could result in missed information, as shown at the top of the page.

Returning to the previous example, when we modify the above chart to show all tools for which either WIP Hours (the red bars) or Effective WIP Hours (the black bars) is greater than 12, we get the chart shown at the top of this page.

Where WIP Hours and Effective WIP Hours are the same (Nitride Deh and Wet Etch5), we know that no qualified tools affecting the WIP in question are down (though they could be unavailable due to being in an engineering state). Where Effective WIP Hours are zero (5xStep01), we know that all qualified tools for that WIP are down. Where Effective WIP Hours exceeds WIP Hours, we know that some number of qualified tools are down. We can visually estimate how many, but we don't know which ones without drilling down.

Looking at the current tool states for the above tools (where the height of each bar tells us how long the tool has been in its current state), as shown on the next page.

Here we see that 5Xstep01 is, as expected, down. Both tools in the Wet Etch5 tool group have been in an engineering state for at least 8 hours. Also of note (though hard to see here) is that Nitride Deh#1, despite having a high quantity of WIP Hours above, is in the Standby-WIP Waiting state. That is, despite being a short-term bottleneck that is currently available to manufacturing, this tool is not being run (perhaps because of a lack of operators to load or unload the tool).



These charts suggest that, based on the information so far, the most immediate priorities are:

1. Get 5xStep01 back online (since there is a significant quantity of WIP waiting that has no other qualified tools available).
2. Consider the Engineering time on the Wet Etch5 tools, and on Nitride Deh3#1, and whether these tools can be returned to production sooner rather than later.
3. Find out why Nitride Deh#1 isn't being run, despite the high quantity of process time needed for waiting WIP.
4. Investigate other tool groups like Coat B to see what is going on with other tools that are not available.

A refinement of this approach would be to filter WIP Hours based on lot priority, to see tools that have a significant amount of time required to process high priority WIP in queue.

Other Ways to Identify Tools in Need of Extra Attention

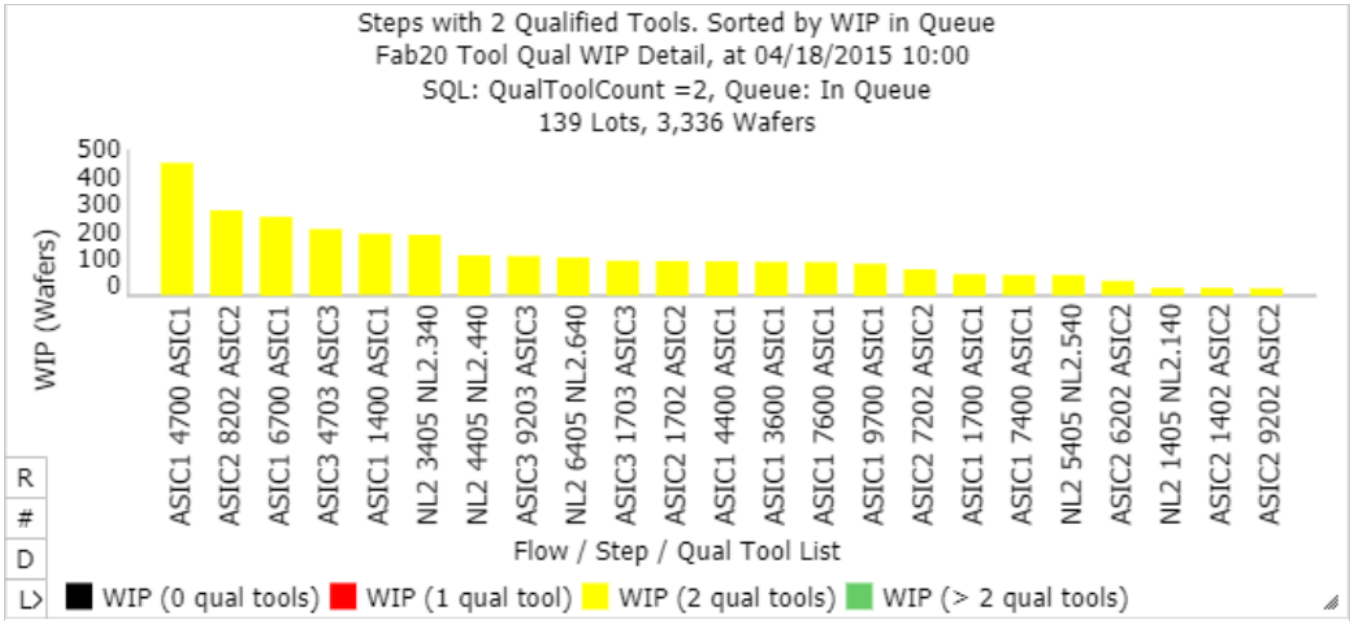
WIP Hours can give a useful snapshot of short-term bottlenecks, but, as discussed back in Issue 20.03, implementing this metric can be a bit challenging in practice. [In fact, while creating the examples for this article, Jennifer discovered a data issue on our demo server requiring the addition of UPH data for batch tools.] There are, of course, other metrics that can be used instead (or in addition). Here are a few suggestions:

Idle WIP by Tool: As mentioned above, some fabs use inventory age to identify problem tools, defining idle WIP as WIP that has been in queue for more than some target, usually either 12 hours or 24 hours. A chart that shows all tools, sorted in descending order of the quantity of idle WIP, can indicate short-term bottlenecks. Returning to our demo server example, we found that the only tools with WIP that had been waiting more than 24 hours were from the Coat C, Nitride Deh, Wet Etch, and Coat B tool groups.

Tool Availability List: This is a chart that we're sure all fabs use in one form or another. In FabTime, the Tool Availability List shows each tool's current status, how long the tool has been in that state, and the quantity of WIP waiting that could be processed on that tool. Filtering this chart for unavailable tools that have high levels of WIP will probably shake out short-term bottlenecks, especially if the focus is on one-of-a-kind or two-of-a-kind tools.

Tool Qualification WIP Detail: This is a chart that we have had in FabTime for quite some time and that we recommend for any fab. For each combination of flow/step/qualified tool list, this chart sums the current WIP, and sums the number of qualified tools (with an option to filter by flow). Looking at this chart highlights single and dual path operations, as discussed in Issue 20.05.

The way to use this chart to identify short-term bottlenecks is to look for WIP that has only one or two qualified tools. In each of those categories, the tools that have the most WIP waiting are strong candidates for further analysis as short-term bottlenecks. When we generated this chart for our demo model, as shown below, the tools that cropped up first were the Nitride Deh tools, 5X Steppers, and Wet Etch5 tools (together with a couple of similar tools), consistent with the example above.



Qual Tools	Flow	Step	WIP Lots	WIP (Wafers)	Qual Tool Count
Nitride Deh#1, Nitride Deh#2	ASIC1	4700	20 List	483	2
5XStep01, 5XStep02	ASIC2	8202	13 List	309	2
Nitride Deh#1, Nitride Deh#2	ASIC1	6700	12 List	285	2
Nitride Deh3#1, Nitride Deh3#2	ASIC3	4703	10 List	240	2
Wet Etch#1, Wet Etch#2	ASIC1	1400	9 List	223	2
Wet Etch5#1, Wet Etch5#2	NL2	3405	9 List	219	2

Turns Pareto: Tool groups where the recent WIP Turns rate (moves / average WIP) is very low are likely short-term bottlenecks. A low turns rate means that either moves are low or WIP is high (or both). However, unlike the metrics discussed so far, turns is not a point estimate. To use turns, we need to decide which time window to use (e.g. the previous 12 hours). This means that turns may be a bit of a lagging indicator. Returning to our example from above, the Nitride Deh, Coat C, and Wet Etch5 tools are near the bottom of the list when we look at the 12 hours preceding the above charts, together with some other candidate short-term bottlenecks.

Moves Pareto: Nearly everyone looks at moves by tool or tool group. Looking for the tool groups that have a significant gap between goal and actual moves can identify short-term bottlenecks. Moves, like turns, is a trailing metric. The effectiveness of using the delta between actual and goal moves to identify short-term bottlenecks will depend on how frequently the shift-level moves goals are adjusted to reflect current priorities.

Forward Path of Hand-Carry Lots: If a fab runs hand-carry lots (see Issue 19.03), tools that these lots are expected to reach during the next shift should also be considered candidates for special focus, particularly tools that have poor availability history.

WIP Pareto for Priority 1 Lots: Tools that have a relatively large number of the highest priority front-of-the-line hot lots are also candidates for special attention. Here "relatively" depends on each fab's situation. Creating a WIP Pareto chart for lots in queue, slicing it by tool group, then filtering for priority 1 lots should give a quick indication of any outliers. Returning to our demo server example, the top two tool groups revealed by this method were FSI Clean4 and Wet Etch5.

Upcoming Scheduled Maintenance: Are there instances where upcoming scheduled maintenance will result in single path operations for an extended period? How about one-of-a-kind tools that are scheduled for maintenance in the next 24 hours? We recommend doing everything in your power to clear out any WIP waiting for those tools before they disappear.

Conclusions

One of the things that makes running a fab challenging is that conditions can change from shift to shift (if not hour to hour). The medium-term bottlenecks are generally well-known and are always excellent candidates for improvement efforts. But on a day-to-day basis, what we need to know are which tools to focus on right now. Ideally, we would like to even peek ahead a bit, to know which tools to focus on to prevent future problems.

We believe that the WIP Hours metric, which was designed for the purpose of identifying short-term bottlenecks, is a good place to start. Together with current tool status information, WIP Hours (and Effective WIP Hours) can suggest places where required capacity is likely to exceed available capacity over the coming shift. Although WIP Hours can be a bit challenging to implement, we do think it is worth considering. Fabs have other metrics that, with a bit of careful targeting, can be helpful in this regard, too. We hope that you have found this discussion useful, and we welcome further discussion on this topic.

Closing Questions for Newsletter Subscribers

What metrics do you use for identifying and tracking short-term bottlenecks in the fab?

Further Reading

- J. Robinson and F. Chance, "Cycle Time and Hot Lots: Updated," *FabTime Newsletter*, Vol. 19, No. 3, 2018.
- J. Robinson and F. Chance, "Defining A Metric for WIP Hours," *FabTime Newsletter*, Vol. 20, No. 3, 2019.

- J. Robinson and F. Chance, "The Impact of Tool Qualification on Cycle Time," *FabTime Newsletter*, Vol. 20, No. 5, 2019.

Past issues of FabTime's newsletter are available for download from https://fabtime.com/newsletter-archives.php. The current password is "FabTimeCommunity" (no quotes, case-sensitive).

Acknowledgements

FabTime would like to thank **Marino Arturo from Skyworks Solutions** for asking the question that inspired this article.

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