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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Welcome

Welcome to Volume 22, Number 3 of the FabTime Cycle Time Management Newsletter. We hope you're enjoying summer wherever you are and are finding the chip shortage positive for your business' bottom line. In this issue we have announcements about some FabTime staffing changes and delivery of our cycle time management course, as well as some highlights from industry news that Jennifer has been sharing on LinkedIn. We also have subscriber discussion about lot splitting for 300mm fabs and managing during a supply crunch.

In our main article, we discuss the impact of rework on fab cycle time, a topic that we have not previously addressed in the newsletter. We share a companion software tip on how to estimate the percentage of rework in FabTime.

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

Community News/Announcements

FabTime Staffing Changes

FabTime is pleased to announce the start of two new employees. **Evan Rozhon** will be working full-time for FabTime as an Application Engineer. Evan recently graduated from CalPoly in San Luis Obispo with a degree in Software Engineering and will be working on technical customer support as well as core software development. **James Purdue** started as an Intern. James is working toward a Computer Science degree from CalPoly and will be helping FabTime with software development for customers and our core software.

We will also be saying farewell to **Caleb Rabbon**, who has worked part-time for FabTime for the past four years doing Network and Computer Systems Admin support while working towards a degree at CalPoly. We wish him all the best in his next position. He will be missed!

FabTime's Virtual Cycle Time Management Course

As announced back in April, FabTime is now delivering a shortened version of our cycle time management course virtually (via Teams) to company sites. As wafer fabs face increasing pressure to deliver product efficiently in the face of the capacity crunch, the course has drawn considerable interest. In the past few months, we have successfully delivered additional sessions to a variety of sites, some software customers and some not.

The course is currently delivered as two two-hour sessions, usually on different days, to minimize disruption to fab schedules. It's designed to bring people from different parts of the fab organization, including manufacturing, process engineering, equipment maintenance, industrial engineering, and production planning, together into a single discussion about how everyone can help drive cycle time improvement. For customers, we spend time identifying specific FabTime charts to help meet these recommendations. For all sites, we spend time discussing which improvement ideas are most promising for that fab.

Here is the current outline of the course:

Part 1: Fundamentals

- Introduction
- The fundamental drivers of cycle time
  - Utilization
  - Variability
  - Number of qualified tools
- Little's Law

Part 2: Implications for Metrics + Operating Practices

- WIP-related metrics to drive cycle time improvement
- Cycle time and equipment downtime
- Other operational recommendations
  - Quick tips on holds, mix, hot lots, dispatching, staffing, and batching
- Conclusions

For more information about the course, please visit our website, or contact Jennifer.Robinson@FabTime.com.

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 links have included:

- Various articles about the worldwide wafer fab capacity crunch and consequent chip shortage, from a suggestion from Intel CEO Pat Gelsinger that the shortage may stretch into 2023 to a recommendation from SkyWater CEO Thomas Sonderman to expand capacity in existing wafer fabs to news of planned expansions by GlobalFoundries that involves adding capacity to the current fab in Malta, NY and building a new fab there. There was also related news about fake chips and chip smuggling efforts.
- Intel, meanwhile, announced an ambitious plan to return to the leading edge in computer chips, introducing more advanced CPUs every year between 2021 and 2025. Tom's Hardware featured an article likening a planned new US fab campus to a small city. Jennifer's LinkedIn post on the topic led to some speculation in the comments (sparked by **Brian Schoonover**) regarding where this new campus might end up.

- An article in the Washington Post about how fabs work and why it can take 3 months and 700 steps or more to produce a finished wafer. This article discusses bunny suits as well as the importance of getting key litho tools back online quickly after a downtime. It's refreshing to see the semiconductor industry getting so much coverage in the mainstream press, we think. GlobalFoundries even made Time magazine.
- Acquisition news, from Nexperia taking over Newport Wafer Fab in the UK to Texas Instruments buying a 300mm fab in Utah from Micron. An addendum to the Newport Wafer Fab news was a report from CNBC that a consortium of investors is putting together a rival bid for the fab.

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

Estimate the % of Moves that were Rework Moves

In this month's main article, we discuss the impact of rework on fab cycle time. One way to measure the impact of rework is to understand what percentage of the moves during a period were rework moves. In FabTime, every WIP transaction has a Rework Yes/No flag that can be set.

All move-related charts have a "Rework:" drop-down filter. You can select "All Lots", "Rework" or "Non-Rwk". This means that you can always estimate the percentage of moves that were rework moves by creating two versions of a chart, one with the Rework filter set to "All Lots" and one with the Rework filter set to "Rework". The ratio of the latter to the former is the percentage of moves that were rework moves.

There is, however, an easier way to find this percentage. The **Moves Trend (Stacked Owner%)** chart breaks down non-rework moves according to the lot owner at the time of the move (e.g., Production, Engineering, Test). This chart also includes a category for Rework moves, expressed as a percent of total moves. The data table includes these percentages, as well as columns displaying the moves in wafers. The quickest way to find the percentage of moves that were rework moves for a period is to generate the Moves Trend (Stacked Owner%) chart over the time period and then look for the "Rework Pct", either on the chart (you can mouse over to see the values) or on the data table. There is also a Pareto version of this chart that lets you look at the rework percentage by area, tool group, or other attribute.

To display only the "Rework Pct" on these charts, check the "Edit Chart" box below the chart. Change the "On Chart" column for the other rows to "Unused", leaving only the "Rework Pct" and "Object Plus Description" rows. Add a custom title to the chart and then save it by adding it to a home page tab.

Although FabTime doesn't track rework as a separate WIP state, we do track cycle time according to whether that time was spent in rework. The cycle time details in the data table for all cycle time related charts break down both rework and non-rework cycle time into the same sub-categories (queue, hold, process, etc.). Thus, you can look, for example, at the **Factory Cycle Time Trend** data table to see the average rework cycle time for all shipped lots.

To add a line showing rework cycle time to a cycle time-related chart, check the "Edit Chart" and "Show All Fields" boxes below the chart. Find the row for "Actual Avg Rework Cycle Time" and change the "On Chart" drop-down from "Unused" to "Line". You can choose a color for the line and choose whether to use the left-hand axis or use the right-hand axis.

We hope you find this tip useful.

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. Thanks!

Subscriber Discussion Forum

Lot Splitting in 300mm Fabs?

An anonymous subscriber asked: "As a wafer fab equipment manufacturer, currently targeting 300mm wafer handling opportunities, I'm wondering if you are aware of any 300mm fabs that are splitting 25 wafer lots (or e.g., any FOUP carrier quantity) across multiple process tools in order to accelerate product flow/reduce lot processing time?"

What to Do in a Supply Crunch

In the June Fab Owners Alliance meeting, Jennifer participated in a breakout session dedicated to wafer fab supply chain issues. Moderators **Fred Bouchard of Sparetech** and **Jose Garcia of Maxim Integrated** asked about what fabs can do during a supply crunch. Jennifer noted that at a time of tight capacity, it's particularly important to avoid lost capacity on key tools, including time spent idle waiting for operators, and time spent down waiting for spare parts or technicians.

Jose mentioned that "magical things happen" in a supply crunch, whereby the engineers figure out better ways to do things, like reducing quals. We thought that "magical things happen" was worth sharing with the subscriber community. Has that been your experience during the recent chip shortage? Are your team members finding innovative solutions to capacity constraints? Or are labor shortages holding you back? Or both?

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

Quantifying the Impact of Rework on Fab Cycle Time

Introduction

During a recent session of FabTime's cycle time management course, a participant asked: "How do other fabs track rework time and where does it fall into these equations (queueing formulas for estimating cycle time x-factor)? Into variability?" We realized that although we track rework moves in FabTime's software, we had never written a newsletter article about the impact of rework on cycle time. We remedy that oversight here.

Rework occurs in a wafer fab when some portion of a lot fails inspection and is sent back to be reprocessed through a sequence of steps, usually photolithography steps. Rework is more cost-effective than scrapping the affected wafers but does have a negative impact on the manufacturing line. The wafers that require rework are generally split out to become a "rework child" lot. The unaffected portion of the lot, known as the parent lot, either waits for the child lot or is sent ahead. Where the parent lot is sent ahead, the rework child may continue on its own or be grouped in later with another lot.

Measuring the Impact of Rework

Estimating the impact of rework on fab capacity is straightforward, provided the fab flags rework move transactions. Any time that a tool spends processing rework wafers is lost capacity. Fab capacity planning models sometimes explicitly treat rework as a loss factor, based on an estimated percentage of time that each tool group will spend processing rework. In FabTime's software, all moves performed on rework lots are flagged accordingly (provided the MES supports this). It's possible to see, for any tool, tool group, or larger grouping, the percentage of moves that were rework moves (see the tip section above for details).

In the SEMI standard for Overall Equipment Effectiveness (OEE), rework, together with scrap, is treated as quality loss. In FabTime's software, this is approximated as Quality Efficiency = (TotalMoves - Scrap - ReworkMoves) / TotalMoves. (The SEMI E79 standard defines Quality Efficiency in terms of processing time.) This means that the impact of rework is captured in tool OEE but is conflated with scrap.

The question for today's article is: how do you measure the impact of rework on cycle time? We see three primary ways that rework affects cycle time:

1. The time that a parent lot spends waiting for a rework child to be reprocessed is a direct addition to the parent lot's cycle time. If the rework child is not reunited with the parent, that rework time will appear as part of the reported cycle time for the child lot.
2. The capacity that tools spend processing rework wafers drives up the utilization of those tools, hence increasing cycle time for all lots that pass through (not just for the rework lot).
3. Processing rework child lots increases process time variability for tools in rework loops. Increased process time variability increases cycle time for all lots that pass through those tools. And, of course, process time variability is often sent downstream as increased arrival variability to other steps.

In the following sections, we'll look at each of the above cycle time impacts in more detail.

[There's also a potential impact of rework on number of qualified tools, if a rework parent is holding up an inspection tool while waiting for the rework child. However, as inspection tools are not normally fab bottlenecks, we won't explore that option further in this article. If your experience has been otherwise, please let us know.]

1. Direct Rework Cycle Time

We haven't seen people report rework time as a sub-state within cycle time. In our software, although all move transactions are flagged according to whether they are rework transactions, we don't report "in rework" as a separate WIP state (the way we do time on hold or time in queue). This is because a lot can be "in rework" and be "in process" or "in queue." So, rework isn't clear-cut as a separate WIP state. We need the details about whether the lot is in queue or in process AND whether the lot is undergoing rework.

We could add a WIP state that is "waiting for rework child." This would capture the cycle time impact of rework for individual lots, at least where the rework parent waits for the rework child. Calculating rework time as a percentage of total time would then seem to be straightforward. However, there would still be the problem of looking back at the history for the lot. Do you report the "waiting for rework child" time or do you report the queue time and process time incurred by the child lot?

This also doesn't help for child lots not reunited with the parent lot. We want to know how much time the child lot spent being reworked, and still be able to distinguish between queue time and process time WIP states during that time.

What we decided to do instead, working with our User Group, was to consistently display cycle time details, including time spent in rework. Rework time is split out into the same buckets as non-rework time, e.g. Rework (pre-process time), Rework (process time), Rework (post-process time), Rework (queue time), Rework (hold time), Rework (transport time), Rework (other time – everything else). So, for shipped lots you can see all time spent in rework, and how much was rework-queue vs rework-process, etc. The same is true for the operation cycle time charts, elapsed cycle time charts, etc. We opted to include this extra level of detail in our data tables, but users can add it to charts for display if needed.

2. Rework Utilization Effect on Cycle Time

Time spent processing rework wafers can be an invisible capacity loss. Where it's significant, as with all capacity losses, it's driving up cycle time. We can estimate the magnitude of this effect by looking at move transactions. Here we take all the move transactions for a tool or tool group over a time period and add up

the process time only (not the queue time) for the rework moves. This process time, as a percentage of total time, is the percent of time that the tool or tool group spent processing rework wafers. Where this is significant for higher utilization tools, we know that rework is driving the tool to a steeper place on the operating curve and increasing cycle time. It's possible to estimate the magnitude of this cycle time effect by comparing the actual tool utilization to the utilization that the tool would have had without the rework wafers.

Here's a quick example. Suppose we have a tool that spent, out of 24 hours:

- 10 hours processing non-rework wafers
- 2 hours processing rework wafers
- 4 hours standby
- 8 hours down or in engineering

The comparison we need to make to estimate the cycle time impact is the difference between the utilization that occurred and the utilization that would have occurred without the rework wafers.

Utilization is defined by SEMI and FabTime as Productive Time / (Productive Time + Standby Time). It is this utilization of the time that a tool is available to manufacturing that drives cycle time at the tool level. In the above example, the tool spent 12 hours processing wafers (including rework wafers) and had 4 hours of standby time, for a utilization rate of 12/(12+4) = 12/16 = 75%.

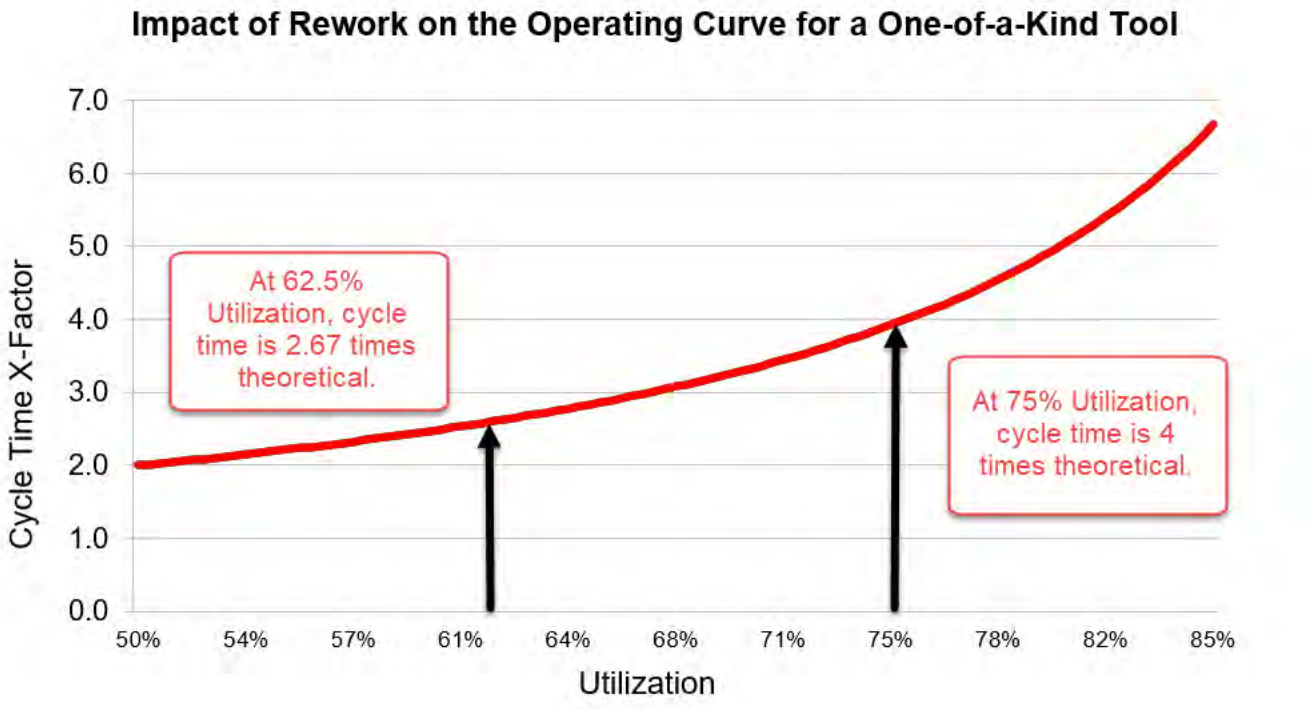
Suppose instead that the time spent processing rework wafers had been standby time, increasing the standby time to 6 hours. In that case, the utilization would have been 10/(10+6) = 10/16 = 62.5%.

For a one-of-a-kind tool with medium variability, we can estimate the average cycle time for each utilization rate as:

Cycle Time X-Factor = 1 / (1 – Utilization)

With rework, that works out to 1 / (1 - 0.75) = 4X.

Without rework, we would have 1 / (1 - 0.625) = 2.67X, as shown on the graph below.



Of course, it might be that the time spent processing rework wafers would have been used in some other way. This estimate is an upper bound on the utilization effect of the rework wafers. But it is quite significant in this example. The effect will be less pronounced in tool groups with multiple tools, or tool groups that have lower levels of variability. The effect will be more pronounced in tool groups that are operating at a steeper place on the operating curve.

FabTime's Characteristic Curve Generator (a spreadsheet tool available for download from our website) can be used to estimate the magnitude of this cycle time impact under different levels of variability. See also Issue 6.05 of the newsletter for more details regarding the 1 / (1 – Utilization) formula.

3. Rework Variability Effect on Cycle Time

Rework also adds to process time variability. Rework children have a smaller lot size, and thus a shorter process time on per-wafer tools. Where rework parent lots continue without the child, the lot size will be smaller for all future steps. Different lot sizes can also add variability (and contribute to lost capacity) on batch tools and cluster tools. In general, rework lots complicate dispatch decisions. [There is some research on how to treat rework in dispatch systems. See the Further Reading section below for examples.] Rework also contributes to arrival variability. Once a rework child is created, it jumps into the rework loop, potentially disrupting flow there.

We could estimate the impact of rework on process time variability for a tool or tool group by first calculating the coefficient of variation (CV) of the sequence of all process times over a time period and comparing that to the CV of the process times for non-rework moves only. Because this would be a bit cumbersome, we would only recommend doing this calculation for tools known to spend a significant portion of their time processing rework. The Characteristic Curve spreadsheet could then be used to estimate the magnitude of the cycle time impact of the two scenarios.

Conclusions

Rework is a known capacity loss in wafer fabs. In this article, we explore ways to assess the impact of rework on wafer fab cycle time. We look at the direct cycle time contributed by the rework operations as well as the indirect cycle time caused by rework's impact on utilization and variability. For understanding the indirect effects, we turn to some simple queueing formulas for estimating cycle time.

Of course, people who work in fabs already know that rework is something to be minimized. But it's our view that the better we understand the impact of inefficiencies like rework on fab cycle time, the more information we have to decide where to focus improvement efforts. We hope you find this article useful and look forward to your feedback.

Closing Questions for Newsletter Subscribers

Have you looked at the impact of rework on cycle time for your fab? Does your fab track rework (or waiting for rework child) as a WIP state? Do you track rework percentage as something to minimize over time? Have we captured the impacts of rework accurately in your view, or are there aspects that we have missed?

Acknowledgements

FabTime is grateful to the members of our User Group who worked with us to revamp our cycle time charts two years ago. As part of this revamp, we now break out cycle time data according to whether a step was or was not a rework step.

Further Reading

Cycle Time Estimates: FabTime's Characteristic Curve Generator is available for download from FabTime's website. See Issue 2.07 for details. This free version of the tool only models one-of-a-kind tools. A more detailed version of the tool, known as FabTime's Operating Curve Generator, is currently only

available to customers of our software or our cycle time management course. The more detailed version includes tool groups with multiple tools, batch arrivals, and hot lots. [FabTime customers can contact Jennifer.Robinson@FabTime.com for the detailed version.] However, the basic version on the website can be used to look at the impact of changes in arrival and process time variability as well as the impact of utilization on cycle time.

For more on the use of queueing formulas to estimate the impact of changes in variability and utilization on cycle time, see Issue 6.05 of the newsletter: The Three Fundamental Drivers of Fab Cycle Time. Past issues of the newsletter are available to subscribers on our website. The current password is "FabTimeCommunity" (no quotes). You can also find a series of queueing models outlined on our website, including one that looks at whole-lot rework.

Literature on Rework and Cycle Time: Two different simulation studies, one of which Jennifer and Frank were involved with, found that simplifying assumptions around rework are a contributor to inaccurate simulated cycle times:

- N. S. Grewal, A. C. Bruska, T. M. Wulf, and J. K. Robinson, "Validating Simulation Model Cycle Times at Seagate Technology." Proceedings of the 1999 Winter Simulation Conference, Phoenix, AZ. Available as a PDF download from FabTime.
- S. J. Hood, "Detail vs. Simplifying Assumptions for Simulating Semiconductor Manufacturing Lines," Proceedings of the Ninth IEEE International Electronics Manufacturing Technology Symposium, 103-108, 1990.

See also:

- S. Y. Hsu, D.Y. Sha, and Y.H. Chang. "An Integrated Dispatching Rule with On-Line Rework Consideration in Wafer Fabrication." *Journal of Manufacturing Technology Management* 20.8, 1166-1182, 2009.
- G. Laubisch, "A Simulation Study of Dispatching Rules and Rework Strategies in Semiconductor Manufacturing." Thesis. Rochester Institute of Technology. https://scholarworks.rit.edu/cgi/viewcontent.cgi?article=6747&context=theses, 2003.
- M. E. Kuhl, and G. R. Laubisch, "A Simulation Study of Dispatching Rules and Rework Strategies in Semiconductor Manufacturing," Proceedings of the IEEE 2004 Advanced Semiconductor Manufacturing Conference (ASMC '04), 325-329, 2004.
- D. Y. Sha, L. F. Hsieh, and K. J. Chen, "Wafer Rework Strategies at the Photolithography Stage," *International Journal of Industrial Engineering – Theory, Applications, and Practice*, Vol. 8, No. 2, 122-130, 2001.
- M. Zargar and B. Ehteshami, "Tradeoffs in Cycle Time Management: Reworked Bonus Lots," Proceedings of the Summer Computer Simulation Conference, 1039-1043, 1991.
- M. Zargar, "Effect of Rework Strategies on Cycle Time," *Computers & Industrial Engineering*, Volume 29, Issues 1–4, Pages 239-243, ISSN 0360-8352, https://doi.org/10.1016/0360-8352(95)00078-F, 1995.

If you know of other articles about the impact of rework, please let us know. We will share them with the subscriber community in the next issue.

Subscriber List

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Top 20 subscribing companies:

- Onsemi (205)
- Infineon Technologies (160)
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- Virginia Tech (7)

New companies and universities this month:

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- Center for Governmental Research
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- GL Automation
- Mitsubishi Chemical
- Silicon Valley Small Manufacturers Forum
- SiMPore
- Thermo Fisher Scientific

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FabTime® Software: If you would like more information about our web-based dashboard for improving fab cycle times, please visit our website. A sample home page and a sample page from FabTime's new Charts menu are shown below.