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 21, Number 6 of the FabTime Cycle Time Management Newsletter. In this issue, we have a couple of FabTime-related announcements, a quick recap of the recent Fab Owners Alliance virtual meeting, and a few links of potential interest to the newsletter audience. Our software user tip of the month is about using the SQL filter on FabTime charts. This allows end users to perform specialized filtering without needing help from IT (or from FabTime). In our subscriber discussion forum, we share a question from a long-time subscriber about process step numbering.

Our main article this month is about Little's Law, a fundamental relationship that drives factory behavior. In addition to providing an intuitive derivation of Little's Law, we discuss the implications of Little's Law on metrics selection for wafer fabs.

Wishing you a peaceful holiday season, and a return to normalcy in 2021! – Jennifer, Frank, Lara, and the FabTime Team

Community News/Announcements

Sites 50 and 51

We don't announce every software sale here in the newsletter, but we did want to mention that we recently started working on our 50th software installation. This is a milestone that Frank and Jennifer have looked forward to for a long time. Site 50 was quickly followed by Site 51, meaning that our installation team will be

keeping busy in the near future. We are grateful to all our customers, long-time and new, and happy to be part of the thriving semiconductor industry.

Fab Owners Alliance Virtual Quarterly Meeting

The quarterly meeting of the Fab Owners Alliance was held virtually December 1-3. The meeting was an opportunity for semiconductor industry peers to network and share insights and best practices on the latest business, and technology trends affecting the electronics manufacturing industry. Jennifer represented FabTime at the meetings and appreciated the chance to connect on screen. Highlights of the meeting included the trivia competition, hosted by Trivia with Budds, and interactive roundtables on these topics:

- Automation, Robotics & Smart Manufacturing
- Staff Allocation (particularly during pandemic) - restructuring shifts, focus on direct labor, moving tools to maximize direct labor, etc.
- Virtual Sales Process
- SPC

There seemed to be a high level of interest in the above roundtable topics. If any subscribers would like to pose a question to continue those discussions here in the newsletter, just let us know.

Although it was the most successful virtual conference she's attended to date, Jennifer, like most of the participants, looks forward to the day when she will be able to attend the FOA again in person. More details can be found at the FOA website: https://www.semi.org/en/communities/foa.

Half-Day Virtual Cycle Time Management Class Now Available

FabTime is pleased to report that we have updated our cycle time management course for remote delivery via Microsoft Teams. The course provides wafer fab production personnel with essential skills and techniques needed to manage cycle time. We have condensed and updated the material, developed over the past 15 years, into four hours of content, designed to be delivered in two two-hour sessions.

This course is designed for production personnel such as production managers, module managers, shift supervisors, hot lot coordinators, equipment supervisors, equipment and process engineers, and production control. Team members will learn how each can contribute to cycle time improvements.

Upon completion of this course, participants will be able to:

- Quantify cycle time relationships between utilization, cycle time, variability, and number of tools.
- Use Little's Law to set WIP targets.
- Select metrics that drive cycle time improvement.
- Apply cycle time intuition to operational decisions.

For more information, contact Jennifer.Robinson@FabTime.com, or visit FabTime's website. Shorter one-on-one course preview sessions, for those considering hosting the course for their company, are also available.

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. Links since the last issue have included:

- An October 12th Star Tribune article (originally shared by Brad Ferguson) about how the SkyWater fab expansion in Bloomington, MN illustrates the rising role of the government in the U.S. chip industry. A related story about SkyWater from the October 8th EE Times reports that SkyWater plans to provide advanced packaging services out of a fabrication facility called the Center for Neovation in Osceola County, Florida.

- An October 19th Science Daily article that reports on research by Sandia National Labs on "a new method that will imbue computer chips that power machine-learning applications with more processing power". The method works "by using a common material found in house paint in an analog memory device that enables highly energy-efficient machine inference operations." This article was originally referenced in SEMI's Global Update newsletter.
- An October 27th Wall Street Journal article by Heidi Mitchell about new research that challenges "the conventional wisdom that the fastest-moving line is a single "pooled" line" and explores situations where dedicated service does lead to shorter wait times. It turns out that in "fields that are knowledge-intensive and have high levels of customer ownership, such as medicine, personal banking or places like the Apple Genius Bar", having a dedicated queue CAN speed up wait times. The servers feel more ownership of the process and respond accordingly. It's still true that you'll get better cycle times in the fab if you can qualify more than one tool for each step. But there may be arguments here for more dedication of operators and technicians. Fascinating stuff (at least for fab IE geeks like us)! See also this Atlantic article by Elissaveta M. Brandon positing that Covid-19 could be the beginning of the end for waiting in line in general.
- A Stanford News Report from October 28th on new research that has found a correlation between heavy media multitasking and memory problems. No, correlation is not causation. But parents of a tween or teens may well want to pay attention.

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.

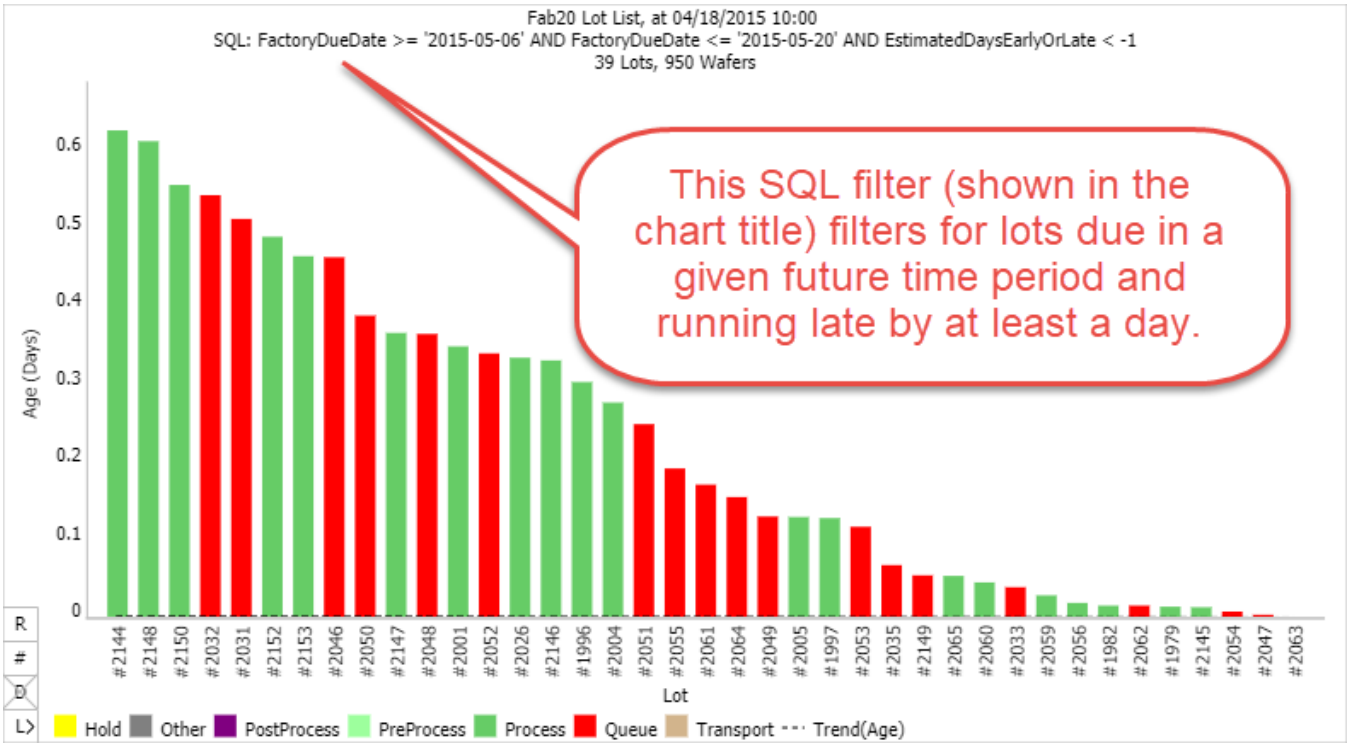
FabTime® User Tip of the Month

Use FabTime's SQL Filter to Refine Chart Results

A FabTime user reached out to us the other day to ask what the "SQL" filter, visible as part of the filters on any chart page, does. The SQL field allows end users to do extra types of custom filtering on a chart without needing help from IT. The SQL filter modifies the data request that your browser sends to FabTime to add extra conditions not readily captured by the standard filters. For instance, you could restrict an hourly trend chart to only shows periods between 9:00 am and 11:00 am. Or you could filter the Tool WIP and State List chart to only show tools that have been in their current state for more than 12 hours (or to exclude tools that have been in their current state for more than 3 days, to get rid of outliers).

For any chart, if you click on the Help button, you'll see a section that tells you what fields can be used in the SQL filter. There's a link at the top of that list that takes you to a Help page outlining how to use the SQL filter. The available fields also appear in a drop-down list when you put your cursor in the SQL filter. Here are just a few examples of SQL filters:

- On a moves lot list chart, restrict to lot moves with 5 units or less: SQL Filter: LotSizeUnits <= 5
- On a moves lot list chart, restrict to lot moves where the lot's current status is shipped: SQL Filter: CurrentStatus = 'Shipped'
- On a WIP lot list, restrict to lots having either Priority=D OR Owner=P: SQL Filter: PriorityClass='D' OR Owner='P'
- On a WIP lot list, restrict to lots with a factory due date between two dates, AND that are estimated to be ship at least one day late: SQL Filter: FactoryDueDate >= '2015-05-06' AND FactoryDueDate <= '2015-05-20' AND EstimatedDaysEarlyOrLate < -1. This is shown below.



In short, the idea behind the SQL filter is to let you do things that you might not be able to do with the regular filters. Here's one last example: remember back in Issue 21.04, when we used the WIP hours pareto chart to generate a list of short-term bottlenecks? That was done using a SQL filter (EffectiveWIPHours >12 OR TotalWIPHours >12).

We hope that 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 (note new link). Thanks!

Subscriber Discussion Forum

Process Step Numbering

Sanjay Rajguru (Redlen Technologies Inc.) wrote: "I'm looking for some guidance on the definition and creation of process step numbering. Is there a document that describes the best practices for this, primarily for defining a process flow?"

FabTime Response:

We do not, unfortunately, know of any such document. From what our installation team has seen, this process varies by company. Here are some notes from the team on what they've seen.

At one of our sites, they number the workcenters and then use an alphabetic designation (a/b/c) for steps within the workcenter. Another site has an MES that is limited to four digits for operation, so this site started with numbers and then added alphabetic detail as time passed. Some of our other sites filter on a flow the site can order by operation using a combination of letters and numbers. Some sites use recipe to map to the FabTime operation and then use detailed numbers of the lower level operations. We've also seen:

- A site using a four-digit operation that is route specific.
- A site that setup their steps to start with a particular digit for each workcenter so if they filtered on step 2* they knew it was for photo vs. filtering for step: 3* which was plate.
- A site that doesn't have any step numbers and instead just looks at data at the tool level.

- A site that has step numbers that have the format XXX. XXXXX where the first numbers before the dot are segment-related and the numbers after the dot are ordered by process steps.

So, it seems like there are two parts to this question in practice at our sites:

- What is the standard; and
- How can the standard be used for ordering?

From what we can tell, there is no broader standard for this. But perhaps another subscriber will prove us wrong. If anyone has anything to share here, please let us know. Thank you!

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

Main Article: Little's Law and Metrics Selection

As we've discussed many times in this newsletter, at the tool group level, utilization, variability, and number of tools together drive cycle time. Occasionally someone asks: "But what about WIP? Isn't WIP also a fundamental drive of cycle time?" In a sense, yes. A fab that sees WIP increase will also see cycle time increase. However, it's more accurate to say that at the same start rate, WIP and cycle time move together. Little's Law is a statement of the relationship between cycle time, WIP, and start rate (or throughput rate) in a manufacturing facility.

These three metrics are related such that you can't change one without changing at least one of the others. This has two implications for fab metrics selection:

1. You can't just decide to reduce cycle time without also changing WIP and/or throughput.
2. Because cycle time and WIP move together (at a given start rate), either one of them can be used as an indicator for the other. This in turn means that you can use WIP as a proxy for cycle time in your metrics, as well as an early indicator of future cycle time.

In this article we will review Little's Law and discuss the implications of Little's Law on selection of fab cycle time improvement metrics.

Little's Law

The relationship between cycle time and WIP was first documented in 1961 in a paper by J. D. C. Little. But we can derive it here using a simple example.

Suppose we have a very small factory in which:

- Average factory cycle time is 3 weeks.
- The factory is initially empty; and
- Each Monday morning 100 wafers are released into the factory.

In this case:

- In week 1 there are 100 wafers in the factory
- In week 2 there are 200 wafers in the factory
- In week 3 there are 300 wafers in the factory

At the end of week 3 (and every week thereafter), 100 wafers exit the factory and 100 new wafers are started. This means (neglecting any yield loss for the moment) that the WIP is always 300 wafers.

Now suppose that demand increases for this factory, such that starts are increased to 150 wafers per week, and that with more work in the factory, average cycle time rises to 5 weeks. Looking again by week, we have:

- Week 1: 150 wafers WIP
- Week 2: 300 wafers WIP

- Week 3: 450 wafers WIP
- Week 4: 600 wafers WIP
- Week 5: 750 wafers WIP

For every week thereafter, 150 wafers exit the factory and another 150 new wafers enter. The WIP remains at 750 wafers.

Summarizing, when start rate is 100 wafers/week and cycle time is three weeks, the average WIP is 300. When start rate is 150 wafers/week and cycle time is five weeks, the average WIP is 750. Clearly, if the start rate was 50 wafers/week and the cycle time was one week, the average WIP would be 50. So, we have:

Average WIP	Start Rate	CT
300 wafers	**100 wafers/week**	**3 Weeks**
750 wafers	**150 wafers/week**	**5 Weeks**
50 wafers	**50 wafers/week**	**1 Week**

That is, the first column (average WIP) is equal to the second column (start rate) times the third column (cycle time). That's it. We've derived the core of Little's Law. Little's Law states that at a given start rate, the ratio of WIP to cycle time equals start rate, as shown in the three equivalent formulas below:

WIP = Start Rate * Cycle Time

Start Rate = WIP / Cycle Time

Cycle Time = WIP / Start Rate

In other words, for a factory with constant start rate, WIP and cycle time are proportional. If we were to start 1000 wafers per week in a fab with an eight-week cycle time, we would expect the average WIP to be 8000 wafers. Well, almost. We do need to correct for yield loss.

What About Yield Loss?

Little's Law holds for all lots. Lots that are scrapped before they finish processing have a shorter cycle time. This means that if we want to use the shipped lot cycle time, we need to include a correction to the above formulas. If scrap occurs relatively linearly across the line, then a reasonable formulation with yield correction is:

WIP = Start Rate * Cycle Time (of shipped lots) * (1 + Line Yield)/2

This treats the scrap as occurring linearly across the line, or, alternatively, as all scrap occurring mid-way through the process.

Another way to think about this is that the yield rate defines the relationship between start rate and throughput rate. If we apply Little's Law using the start rate, and we don't include a yield correction, the resulting estimate for WIP will be too high (we won't be accounting for the scrapped lots). If we instead use the throughput rate in place of start rate in the Little's Law equation, the resulting estimate for WIP will be too low (we won't be including the extra wafers that have been started but not yet scrapped).

For a fab that has a non-linear distribution of scrap across the line, a modified yield correction would be appropriate. The exact form of the yield correction is only likely to have a significant impact on estimates in cases of relatively low yields, as with development products.

Using Little's Law for Your Fab

If you think about your fab's performance in a big picture sense (we start ~1000 wafers per week, our average cycle time is ~six weeks, and, yes, our WIP is ~6000), you should find that Little's Law does hold. We don't recommend getting too bogged down in the computational details of verification. Start rate can vary from week to week. Cycle time varies for different products, and for hot lots vs. regular lots. You need to make sure that you're not excluding any hold time from the shipped lot cycle times that you're using. And so on. Fabs are complex.

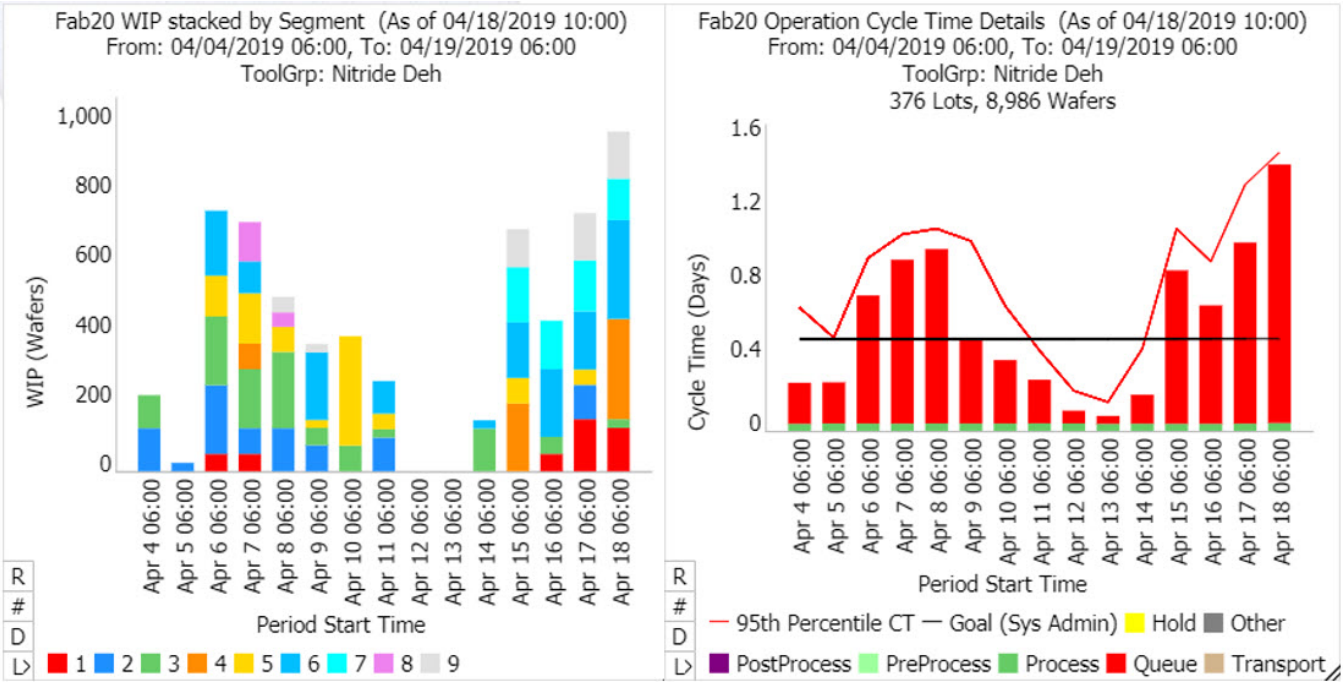
But it's not a question of needing to verify that the formula holds exactly for your fab for the lots that shipped this week. The point is to understand that this fundamental relationship exists and to use this understanding to inform and improve your metrics selection.

The Implications of Little's Law for Choosing Metrics

The general implication of Little's Law is that cycle time and WIP move together. This means that you can't just decide to reduce cycle time without also changing WIP and/or throughput. Variability reduction efforts that reduce cycle time will also reduce average WIP in the fab.

Little's Law means that if your throughput rate is relatively constant and you see WIP levels rising in the fab, you know that cycle time will be rising, too. This is true at the tool group level as well as at the fab level. If you see WIP rising in front of a tool group, operation-level cycle times will be increasing soon, if they haven't already. There may be some lag, of course, because WIP first piles up in queue. Higher operation-level cycle times don't appear until that WIP starts moving out of the tool.

The example below shows WIP (stacked by segment) at a tool group at the start of each day on the left. Per visit cycle times of wafers moving out of the same tool group are shown on the right. While the WIP and cycle time generally track between the two charts, we can see that (on the left-hand side of the charts) the cycle time peak on April 8th lags the WIP peak on April 6th.



In general, Little's Law means that you can use WIP as a proxy for cycle time in your metrics. This is helpful because WIP is often easier to measure than cycle time. It's a point estimate. You don't need to decide what time window to use. You also don't need to wait for lots to ship (or move out of a tool). You can measure the WIP at any time. At a known throughput rate, you can use Little's Law to tell you what WIP level to target to achieve a given cycle time.

Including WIP in your metrics will help keep you focusing on cycle time. Metrics that help capture the impact of WIP (and hence cycle time) include WIP turns (moves divided by average WIP), dynamic x-factor (total WIP divided by WIP being processed on tools), and WIP states (reporting of the time a lot spends in various states, including hold, queue and process).

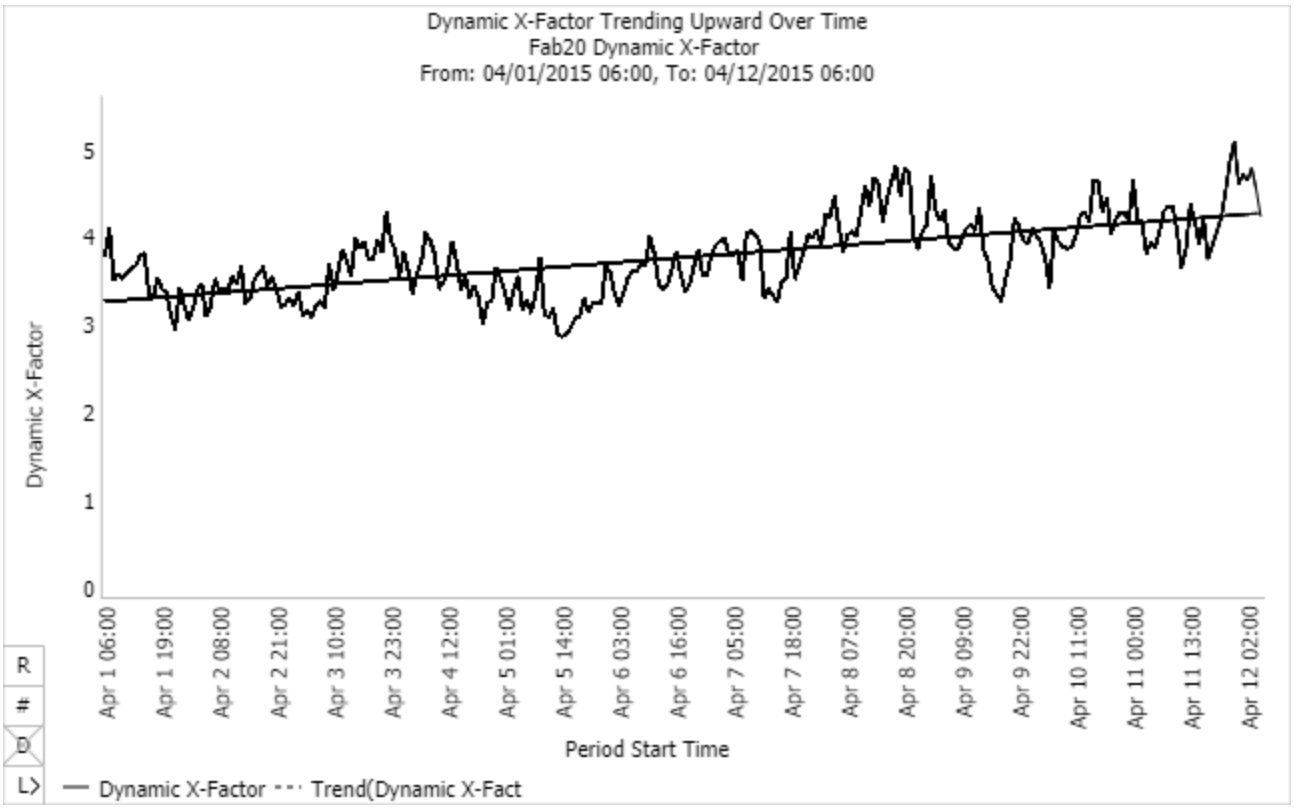
A Forward Look at Cycle Time

Another important implication of Little's Law is that WIP turns and dynamic x-factor, both of which involve measuring WIP, can give you a forward look at fab cycle time.

The fab-level turns rate tells you how many times per day, on average, each wafer in the fab moves through an operation. If you also know how many operations there are in the process flow, you can estimate the future cycle time of the current WIP. For example, suppose that your fab is doing 32,000 wafer moves/day, and the WIP is 8000 wafers. This means that the turns rate is 32,000/8,000 = 4 per day. Each wafer is being moved, on average, four times per day. If the weighted average process flow is 400 steps, then the average cycle time, based on the current turns rate, will be about 100 days. If we see the turns rate start to decline, and we don't take action to improve it, cycle time will start to increase.

Dynamic x-factor (DXF) is a point estimate that people often graph like a control chart. Each point records the total WIP in the fab divided by the WIP in running on tools. DXF is usually reported on an hourly basis. While the exact value will vary from hour to hour, DXF fluctuates around some average. It can be shown (see Issue 9.04) that in the long run, DXF can be used to predict shipped lot x-factor, though there are some issues that complicate this prediction in practice. If you see DXF trending upward, then, you can expect that unless corrective action is taken, shipped lot cycle time will increase in the future.

In the example below, although there is quite a bit of variability from hour to hour, fab-level DXF appears to be trending upward. DXF goes from averaging ~3.4X to averaging ~4.4X over the twelve-day period of the chart.



Conclusions

We talk often in this newsletter and our course about the three fundamental drivers of cycle time at the tool level: utilization, variability, and number of tools. Also fundamental for understanding how factories work is Little's Law, which states that cycle time is equal to WIP divided by start rate (or throughput rate, with a yield rate to convert between the two). Little's Law can be mathematically proven (see the reference below). But we feel that an intuitive derivation like the one in this article is more meaningful for building understanding.

Little's Law means that if you want to reduce cycle time in your fab, you can either reduce WIP or increase throughput. For most fabs, throughput is gated by the capacity of the bottleneck, and cycle time reduction efforts tend to focus on WIP management.

Little's Law also means that, absent changes in throughput rate, WIP and cycle time move together, which has implications for metrics selection. You can use WIP as a proxy for cycle time and (with a bit of additional information) as an early indicator of future cycle time problems. Little's Law is why, as cycle time has become more of a focus for fabs over the years, traditional metrics like moves and tool availability have been supplemented by cycle time-focused metrics such as WIP turns. We'll talk more about metrics selection for cycle time improvement in a future article.

Closing Questions for Newsletter Subscribers

Is there a broad understanding of Little's Law in your fab? Have you formally taught Little's Law, or is this more of an intuitive understanding? Does your fab use WIP as a proxy for cycle time in metrics?

Further Reading

FabTime first wrote about Little's Law back in our third newsletter issue (Volume 1, No. 3). We also included Little's Law in a tutorial published on our website. You can also find an explanation of Little's Law in the textbook Factory Physics by Wallace Hopp and Mark Spearman. Little's Law even has a Wikipedia page.

If you'd like to go to the source, John Little first wrote an intuitive explanation of Little's Law in 1954. He published a proof of the relationship in the journal Operations Research in 1961. You can purchase that article here.

This article mentions FabTime newsletters 1.03 and 9.04. All past issues of FabTime's newsletter are available to subscribers for download from our website. Contact Jennifer.Robinson@FabTime.com for the current password.

Subscriber List

Total number of subscribers: 2820

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- Infineon Technologies (152)
- Micron Technology, Inc. (117)
- Intel Corporation (115)
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- Tower Semiconductor (34)
- Honeywell (30)

Top 3 subscribing universities:

- Ecole des Mines de Saint-Etienne (EMSE) (9)
- Arizona State University (8)
- Virginia Tech (7)

New companies and universities this month:

- CyberOptics
- Marki Microwave
- PEER Group

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