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FabTime® Newsletter

Volume 25, No. 4 July 2024

Information

Publisher: Acquired by INFICON in early 2024, FabTime has been helping fabs with cycle time and performance improvement since 1999. The FabTime flexible reporting software module, cycle time management course, and this newsletter are now part of the INFICON Intelligent Manufacturing Systems (IMS) group.

Editor: Jennifer Robinson, Cycle Time Evangelist for INFICON

Date: Wednesday, July 17, 2024 – Vol. 25, No. 4

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Keywords: OEE; Metrics; Equipment Downtime

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Welcome to the FabTime Newsletter

Welcome to Volume 25, Number 4 of the FabTime Cycle Time Management Newsletter. It was great seeing some of you at SEMICON West last week! Thanks to everyone who stopped by the INFICON booth. In this issue, we have announcements about a new SEMI Women in FOA forum, a webinar that I presented via the FOA about cycle time, and, most importantly, our upcoming in-person User Group Meeting. If you are a FabTime®, FPS, and/or FabGuard® customer, I urge you to **pre-register now**! We also have a heads-up that the archive of past newsletter issues on the old FabTime website will only be available for a short time. If you would like access to those issues, download them soon!

Our software tip of the month is about generating scrap charts in FabTime. We also have a subscriber discussion about using OEE in factories (front and back end) and another about metric trees for fabs. Our main article is about the impact of downtime on the fundamental drivers of cycle time and what that implies for metrics selection. Tracking the right equipment reliability metrics and using them as a basis for communication between fabs and equipment suppliers is a way to drive cycle time improvement.

Thanks for reading! – Jennifer

Community News/Announcements

Sign up now! Join the FabTime team at the INFICON IMS 2024 User Group Meeting

As previously announced, the INFICON IMS User Group Meeting/Smart Manufacturing Symposium will be held October 15 – 17 in Austin, Texas. The event will have multiple sessions dedicated to FabTime®, FPS, and FabGuard® over the course of three days. Of special interest to newsletter subscribers, **Jennifer will lead an abridged session of the FabTime cycle time management class** for any UGM attendees who are interested.

This will be the FabTime team's first time participating in this event, and we hope that many of our customers will attend. There will be a day-long session dedicated to FabTime topics, in addition to the cycle time class and other sessions of interest to FabTime software users.

The in-person User Group Meeting will be held in Austin, TX on October 15-17

Plan for lively discussions and collaboration on a variety of topics, including:

- FabTime
- AI/ML
- Sensors and Sensor Applications
- Scheduling
- Dispatch, Delivery, and Location Tracking
- Operations Dashboards and Reporting
- Subfab, Facilities, and Green operations
- Autonomous Control Room and System Integration
- Maintenance Management and Predictive Maintenance
- FabGuard and FDC
- Digital Twins, Databases, and Infrastructure

Sessions will include product overviews and roadmaps, working groups and panel discussions, customer presentations, and training. Customers of FabTime, FPS, and/or FabGuard products are welcome and encouraged to attend and to participate in discussions and presentations.

If you are interested in attending, please complete the pre-registration form. This will help us to finalize session planning and ensure that you receive follow-up information. As an incentive, anyone who pre-registers before August 15th (including those who have already filled out the form) will be entered in a lottery to win one of three cool prizes! Contact Mike Neel or your INFICON site lead for more information, especially if you are interested in presenting or would like to suggest a topic.

We hope to see you there!

Remember: you will need to resubscribe to the newsletter later this year

As previously mentioned, we will be migrating this newsletter over to the INFICON mailing system. In the next issue, we will share a link that you'll need to follow to re-activate your subscription. We apologize in advance for any inconvenience.

Download past FabTime newsletter issues while they are still available

In related news, the FabTime Newsletter Archive on the old FabTime website will be discontinued soon. **Now is the time to download past newsletter issues,** if you are interested in keeping them. Individual PDF issues are available, as well as a zip file containing all the past issues. There is also a link to download the full version of our Excel-based Operating Curve Spreadsheet tool. Don't miss your chance! The password is FabTimeCommunity.

Download the video from our FOA Fab Star Webinar on Cycle Time

Jennifer was also pleased to represent INFICON via the recent SEMI webinar, "Maximize Your Manufacturing Efficiency: Gain Insight into the Three Fundamental Drivers of Fab Cycle Time," hosted by the FOA Star Webinar series.

In this presentation, Jennifer introduced the fundamental drivers of fab cycle time (utilization, variability, and number of qualified tools) and shared how improving these leads to increased fab profitability.

Examples included:

- Increasing fab capacity by reducing forced idle time on key tools.
- Reducing fab cycle time by showing stakeholders the impact of hot lots on regular lot cycle time (and thus driving reductions in the quantity of hot lots).
- Improving cycle time of new products by demonstrating where "soft dedication" or insufficient tool qualification is occurring.
- And more.

Jennifer Robinson, Cycle Time Evangelist, presented this FOA Fab Star webinar in June

If you attended the webinar, thank you! If you missed it, you can watch the video of the webinar on the INFICON website (scroll to bottom of the page) or the SEMI website. Please reach out to Jennifer directly if you would like copies of the slides and/or the spreadsheet tools referenced in the presentation, or if you have any questions about the material.

Enjoy a quick recap of the first-ever Women in FOA forum

INFICON was proud to sponsor the first-ever Women in FOA forum, held at InnovaFlex in Colorado Springs, and to have Jennifer speak at the event. As a long-time member of the SEMI Fab Owners Alliance, accustomed to being one of a handful of women at each meeting, Jennifer found the FOA's new focus on welcoming and encouraging women invigorating. The group outing to a local Escape Room provided opportunities for both fun and bonding.

The Women in FOA group members smile after successful escape room adventures.

The panel discussion in the main meeting, hosted by Michelle Williams from SEMI and featuring Lindsay Pack of InnovaFlex Foundry, Stephanie Morris of Microchip Technology Inc., Carrie Rogers of Broadcom, and Melissa Veltman of Siconnex, also generated a very positive response. Jennifer looks forward to participating in the Women in FOA group going forward, and thanks the FOA team for adding this new focus. If you are a woman working at an FOA member company, please contact Jennifer for more information.

Check out recent industry news 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 included:

- A Rest of World article by Viola Zhou that takes a deep dive into how cultural differences between the US and Taiwan are affecting engineers working on TSMC's wafer fab construction project in Arizona. This paragraph especially caught my attention having just written about fab status meetings: "One former American TSMC engineer who trained in Taiwan said his manager instructed him to follow along with daily handover meetings, which were conducted in Mandarin, just by looking at the associated PowerPoint presentations. 'I was mind-blown at his expectations,' he told Rest of World. 'I love challenges and pushing myself, but this was lunatic-level leadership.'"
- A report from Semiconductor Digest that the Semiconductor Industry Association and Boston Consulting Group (BCG) are projecting that "the United States will triple its domestic semiconductor manufacturing capacity from 2022—when the CHIPS Act was enacted—to 2032. The projected 203% growth is the largest projected percent increase in the world over that time."
- A report from McKinsey that has serious implications for the labor shortage in the semiconductor industry, if correct, that "more than half of semiconductor and electronics employees are considering leaving their current jobs, citing a lack of career development and limited workplace flexibility as the main reasons."
- A piece by Elizabeth Allen in Semiconductor Engineering suggesting that hiring more veterans could help mitigate the labor shortage in the industry. Allan writes that a "Penn

State-led model to bring veterans into the chip industry could scale for broad workforce development… Along with general technical skills, veterans tend to have an accelerated learning ability, a high respect for procedures, and the ability to perform efficiently under pressure, which are ideal traits for technicians and engineers.” This idea also came up at the May SEMI Fab Owners Alliance meeting.

- An article by Sharon Terlep in the WSJ about Boeing that made me think of the semiconductor industry. Many senior mechanics retired from Boeing during Covid, and the company has had to hire many younger workers. “The result: factories populated by new employees, many of them younger than their predecessors and with no experience related to building airplanes. Gone were many of the seasoned workers with the know-how to handle problem parts or glitchy equipment, or to point newer colleagues to the right procedures tucked deep inside digital tutorials.” Sound familiar, anyone? At Boeing, executives say this labor turnover has contributed to quality issues. I wonder if that's been the case (or will be the case as the labor shortage evolves) in fabs. [See also this WSJ opinion piece by Cole Kelley, who passed up college to be an HVAC technician.]
- An article by Thomas Beeg that readers of this newsletter will likely enjoy, his third in a series about managing test wafers in the fab. His central point in the piece is that: “(he) think(s) to have a chance to be successful, the general FAB mindset needs to be that test wafers have the same importance as production or engineering wafers.” We do allow people to display and filter test wafers (together or separately from other WIP) in the FabTime reporting module, if they are tracked in the fab MES.

For more industry news, connect with Jennifer on LinkedIn.

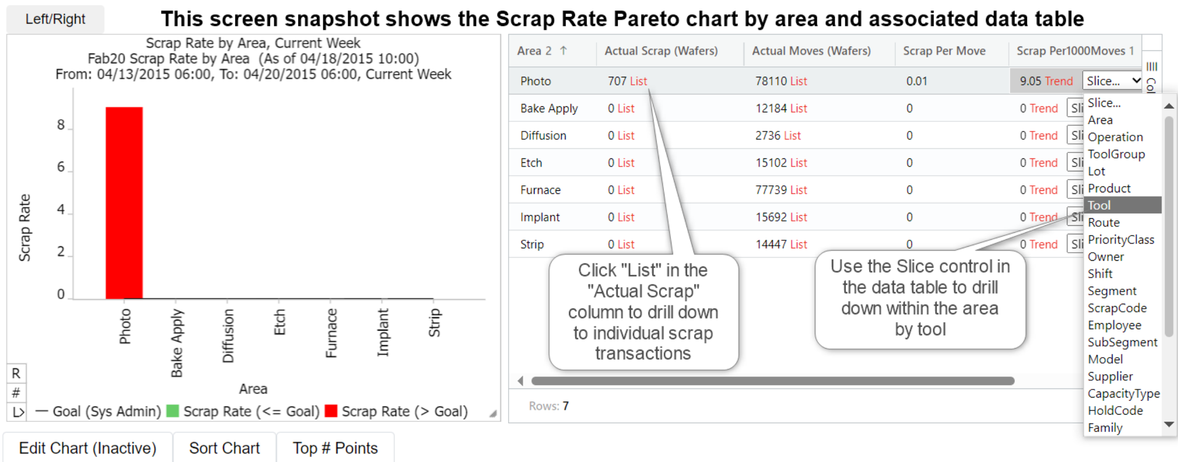
We welcome the opportunity to publish community announcements, including calls for papers. Send them to Jennifer.Robinson@inficon.com.

FabTime Software Tip of the Month

Learn how to generate Scrap Rate charts in FabTime

A long-time customer asked us recently how to generate failure rate charts in FabTime. There is a standard chart in FabTime to do this. We are highlighting it here, in case other customers have also had difficulty finding this information. To generate a chart showing the failure rate by tool:

1. Enter “Scrap Rate” in the FabTime search box and select “Scrap Rate Pareto.”
2. The resulting chart defaults to show you the scrap rate data, measured as number of wafers scrapped per 1000 moves, by area for the current day. To view by tool or tool group, change the “Slice” drop-down at the bottom of the big set of filters to the left of the screen, and click “Go.” Alternatively, use the Slice drop-down in the “Scrap per 1000 Moves” column of the data table to drill into one of the selected areas, selecting Tool or Tool Group, as shown below.
3. Filter as needed to narrow down the set of tools included.
4. Change the time window for the chart to something longer to get a more meaningful dataset for comparison across tools. The chart below includes a week of data.
5. In the data table, click “List” for any row in the “Actual Scrap (Wafers)” column to see a list of the associated individual scrap transactions.



We hope you find this tip useful in driving improvement efforts in your fab.

Subscriber Discussion Forum

Has anyone created Metric Trees for wafer fab metrics related to CT?

Lien Bosmans from Randstad Digital (consulting on a project for IMEC) wrote: "I'm wondering if you know of initiatives to create a metric tree for metrics like cycle time and WIP? I'm new to the world of fabs. While I find it wonderfully interesting, it's also challenging for me to tie all the different metrics together. The metric trees I know of are defined for B2B SAAS companies (as described, for example, in this blogpost) and I couldn't find anything similar for fab metrics, but maybe I just didn't look in the right places yet?"

Response from Jennifer: Prior to receiving your message, I was not familiar with metric trees and have not seen them used for semiconductor fabs. I do think it's an interesting concept. For other readers, the idea of a metric tree is (per the above link) to "create a simplified representation of how inputs flow into outputs."

I think there could be real value in defining the "North Star" metrics for fabs and then identifying which other metrics are inputs to those. There are many metrics used in fabs, and I agree that it's challenging to tie them together. For instance, cycle time at the factory level is driven by cycle time per visit at the tool-level. Tool group level cycle time is driven by utilization, variability, and number of qualified tools. Tool utilization is driven by start rate, product mix, tool availability and UPH rates, etc.

My colleague, **Holland Smith**, pointed out that the E124 SEMI Specification for Definition and Calculation of Overall Factory Efficiency (OFE) and Other Associated Factory-Level Productivity Metrics has a chart that shows how various lower-level metrics all feed into OFE. There are eight base metrics at the bottom of the graph, including average cycle time and availability efficiency. This chart is something like a metrics tree, but it is quite complex, so I don't think it fulfills the definition of a "simplified representation."

I will keep this on my list of potential future newsletter topics: metric trees for the key wafer fab productivity and cycle time metrics. However, **if any subscribers know of a source in which this work has already been completed, please do let us know**. Thank you!

How important is OEE as a metric for factories, and does that vary between front and back end?

CC Lam from onsemi wrote: "The topic of daily fab status meeting made me think of some questions regarding OEE in factories. I worked for eight years in a wafer fab, but transitioned seven years ago to assembly & test (AT) operations. I don't recall OEE being a major issue in wafer fabs back when I worked there. Now, however, for AT, OEE is getting a lot of attention. I've seen some managers asking for product family-level OEE, which doesn't even make sense because OEE is related to equipment and equipment is usually cross qualified for various product families. Even when demand is soft, they are looking at this metric. I think that during low demand periods, OEE is not as important since most equipment will have excess idle time. Usage will naturally be lower hence lower OEE (assuming no equipment shutdowns). My questions are:

1. How important OEE is in those daily meetings?
2. Are the wafer fabs as obsessed with OEE as AT?
3. Who/which dept in wafer fabs looks at OEE?"

Response from Jennifer: I agree with CC completely that product family-level OEE doesn't make sense. OEE is an equipment-level metric. A fab might look at something like different UPH rates for different product families, but that's not OEE. I also agree that driving for OEE on equipment that has excess idle time due to low utilization is not useful. It still makes sense to look at the other OEE loss factors for such tools, but not the loss due to standby time when there's no WIP there. But it's my opinion that OEE is most useful for bottleneck tools. To CC's questions:

1. **How important OEE is in daily fab status meetings?** This probably varies by factory. OEE is one of many things that is looked at in daily fab status meetings, but it should only be looked at day to day (as a number) for bottleneck tools, and/or for tools where the OEE is much worse than expected.
2. **Are the wafer fabs as "obsessed with OEE" as are AT factories?** It sounds to me like strong interest in OEE may have emerged more recently in assembly and test sites as people have learned about OEE as a metric. Fabs went through this phase earlier, and since then have learned to use OEE more strategically, focusing on the strengths of the methodology, but also understanding the limitations. I suspect that OEE use in AT sites will follow a similar path, but I don't have data to back this up. [Maybe other subscribers do?]
3. **Who/which dept in wafer fabs looks at OEE**? Fabs likely do look at OEE as part of the daily status meeting, but it's probably Industrial Engineers who would lead any in-depth analysis of OEE results. This is because the real value of OEE lies in digging into the various loss factors: Availability Loss, Rate Loss Operational Loss, Performance Loss, and Quality Loss. Different departments contribute to each of these losses, so it makes sense to have IEs take a first pass, and work with equipment and process engineers, as well as operations, to drive improvements.

We've written about OEE in several past newsletter issues, including:

- In-Depth Guide to OEE Resources (Issue 2.4)
- OEE and Cycle Time (Issue 3.1)
- Computational Issues in Estimating OEE (Issue 11.03)
- Using OEE to Enhance Factory Performance (Issue 12.05)
- Implementing OEE for Cluster Tools (Issue 16.06)

We also have extensive detail about OEE calculations in the OEE Chart Help inside the FabTime software. **Do any other subscribers have additional responses to the above questions about use of OEE charts, particularly in assembly and test factories?**

We welcome the opportunity to publish subscriber discussion questions and responses. Simply send your contributions to Jennifer.Robinson@inficon.com.

Main Article: Improve Fab Cycle Time by Tracking the Right Equipment Reliability Metrics

When asked to name the factors that contribute the most to cycle time in their fabs, people give a range of responses. They might mention bottlenecks or product mix or time constraints between process steps. But far and away the most common response over the 20+ years we've been asking this question is: **equipment downtime.** Every fab team that we've ever spoken with has indicated that they believe they could get better cycle time if only the tools were more reliable.

This is not to hand out blame to equipment vendors. (INFICON sells a range of sensors that are used in semiconductor equipment.) Cutting edge wafer fabs are constantly pushing the boundaries of technology, meaning that fabs are using leading edge tools that may not yet have all the kinks worked out. Older fabs, in contrast, struggle with equipment that has been in use for many years and may not be as widely supported as it once was. This is not to blame fab maintenance technicians, either, for the same reasons. Maintenance techs also suffer from the common challenge of not being able to be in two places at one time, which is hardly their fault.

What we think IS partially to blame is a lack of understanding about which equipment reliability metrics, if improved, would be most helpful in reducing fab cycle time. People track mean time between failures (MTBF) relentlessly. But MTBF is almost meaningless for cycle time improvement. People track OEE on all the tools, even though OEE in its default formulation is not relevant for non-bottleneck tools (though certain OEE loss factors remain helpful). Fabs pressure equipment suppliers to deliver better equipment reliability. But it's not clear that everyone involved has the same understanding of what "better equipment reliability" means.

What's meaningful for cycle time in terms of equipment reliability are four things:

1. Overall availability
2. Duration of unavailable time, measured as mean time to repair (MTTR) and/or green-to-green time
3. Repair time variability
4. Availability variability

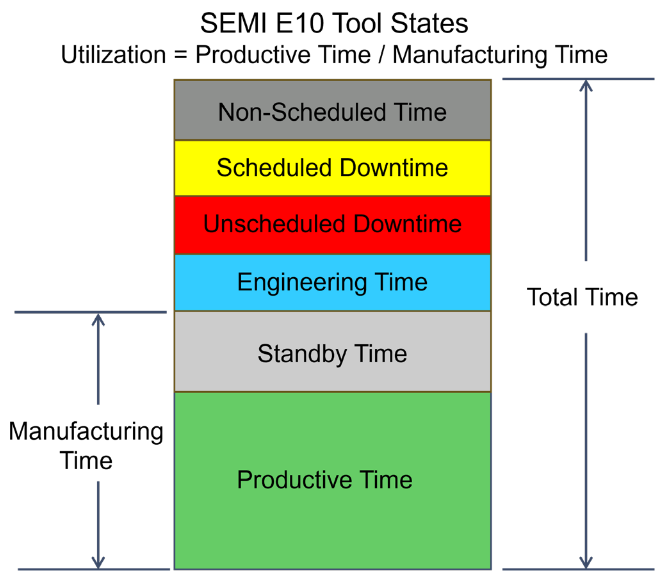
In this article, we will explore why these four aspects of equipment downtime drive cycle time and propose associated metrics and actions to improve them. It is our hope that fab personnel, especially maintenance engineers, as well as equipment suppliers will find this article a helpful reference to improve understanding of and communication about equipment reliability.

How downtime affects cycle time: definitions

Downtime hurts cycle time by degrading each of the three fundamental drivers of cycle time: utilization, variability and number of qualified tools. See Issue 22.04: Fundamental Drivers of

Wafer Fab Cycle Time for an overview of how these factors impact cycle time in general. Here, we'll talk about each of these, in turn, in the specific context of equipment downtime.

First, a few definitions:



Utilization of a tool is the ratio of productive time to manufacturing time, where manufacturing time is the total time that the tool is available to manufacturing to process wafers. This definition is from the SEMI E10 Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM), which classifies the tool states as shown to the right.

We have: **Utilization = Productive Time / Manufacturing Time**

= **Productive Time / (Productive Time + Standby Time**)

In general, as standby time gets small, utilization becomes high. With no standby time, utilization will equal 100%. With no productive time, utilization will equal zero.

X-Factor is a metric for tracking cycle time, recorded as total cycle time / theoretical (best case) cycle time. X-factor can be measured at the factory level or at the operation level. When measured at the operation level, it typically includes all time from when the lot moves out of the prior step until it moves out of the current step, including travel time, queue time, and process time.

An **Operating Curve** is a graph that shows cycle time x-factor on the y-axis and utilization on the x-axis. Operating curves are used to show the impact of utilization and other factors on x-factor.

The operating curve for a one-of-a-kind tool, under certain assumptions, follows this formula:

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

What this formula means is that as utilization approaches 100%, in the presence of any variability, cycle time gets very high. Only when the variability factor is zero is cycle time x-factor equal to one (no queue time).

When the variability factor is equal to one, the equation for x-factor reduces to a simpler form:

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

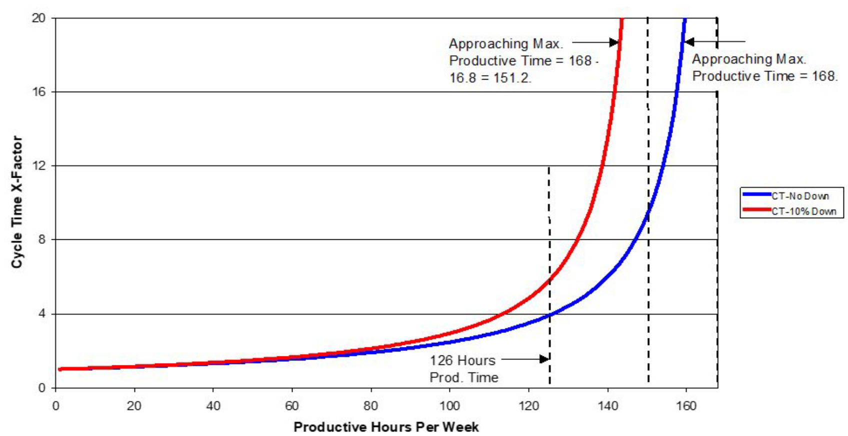
This equation shows that as utilization approaches 100%, we have one divided by zero, which approaches infinity. Of course, we don't have infinite cycle time in practice because we don't have infinite WIP. But what these equations illustrate is that we need for there to be at least some standby time to achieve good cycle time. Now let's look at how downtime affects utilization (and hence cycle time).

Downtime increases utilization by taking away standby time

We can see from the above definitions, particularly from the schematic of the E10 Tool States, how downtime impacts utilization. When productive time is held constant, both scheduled and unscheduled downtimes reduce standby time, thus increasing utilization. Increasing utilization in turn increases cycle time.

Let’s look at an example. Suppose we have a tool with combined scheduled and unscheduled downtime of 16.8 hours per week (10% of total time), no engineering time, and no non-scheduled time. This puts us on the red operating curve shown to the right, where we hit 100% utilization when the tool is run 151.2 hours per week (168 hours – 16.8 hours). As productive time approaches 151.2 hours per week (the rightmost part of the red curve), cycle time gets very high. If the actual productive time in a week is 126 hours, then the standby time will be 151.2 – 126 = 25.2 hours, and we’ll have:

Converting 10% downtime into standby time lowers utilization



Utilization = 126 hours / 151.2 hours = 83.33%

Following the simple formula for x-factor, we have:

X-Factor = 1 / (1 - .8333) = 6X

But, now suppose we can convert the 16.8 hours per week of equipment downtime to standby time. What this does is push out from the red curve to the blue curve, where 100% utilization is reached when the tool is run 168 hours per week. If we have the same 126 hours per week of productive time as in the example above, we’ll have 168 – 126 = 42 hours of standby time, and our effective utilization will drop to 126 / 168 = 75%. If we once again follow the simple formula for x-factor, we will have:

1 / (1 – Utilization) = 1 / (1 - .75) = 4X.

That is, converting 16.8 hours of downtime (10%) into standby time reduces the average cycle time by ~33%, from 6X to 4X. Because the operating curve is non-linear, the closer we are to the steep part of the curve, the greater the impact will be from converting downtime into standby time.

Any hours (or even minutes) of scheduled or unscheduled downtime that can be converted to standby time increase the tool’s buffer capacity and keep it away from the steep part of the operating curve.

What does this mean in terms of metrics that capture the impact of downtime on utilization?

Equipment engineers can support cycle time improvement by ensuring that tools have the highest possible availability (the lowest possible amount of combined scheduled and unscheduled downtime), on a day-to-day and week-to-week basis.

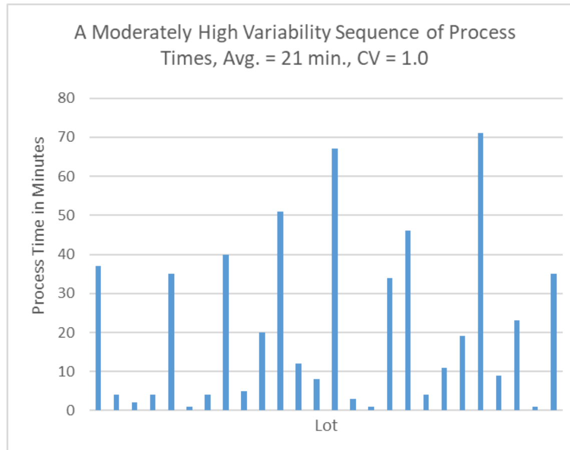
Now, let’s consider variability.

Variability from downtime changes the shape of the operating curve

Variability changes the shape of the operating curve. Remember that our formula for the operating curve for a one-of-a-kind tool as shared above was:

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

The formula for the Variability Factor is: $(CV_a^2/2) + (CV_p^2/2)$, where CV_a is the coefficient of variation of time between arrivals and CV_p is the coefficient of variation of the process times.



Coefficient of variation is a statistical measure that records how far things are away from the average. A series of values that are all the same would have a coefficient of variation of zero, while a higher variability set of values might have CV= 1, as shown in the example to the right. What the formula for x-factor shows is that the higher the variability factor, the higher the cycle time. And the higher the utilization, the greater the impact of the variability factor.

There's a more detailed formula for the operating curve that we have coded into our Operating Curve Spreadsheet (available for download from the FabTime Newsletter Archive). That formula includes multiple tools, batch arrivals, and hot lots. It also includes an approximation for a single downtime distribution.

We will spare you the full complexity of the formula (see the CT Calculator Details sheet of the spreadsheet for more information), but what's relevant here is that it replaces CV_p^2 (the base coefficient of variation of process times) in the variability factor with a calculated system variation value that includes the impact of equipment downtime on the effective process time experienced by each lot. The relevant portion of that formula for looking at downtime is this term, which is added to the base process time variability:

Downtime Variability = [Availability*(1 – Availability)] * (MTTR/Avg. Process Time) * $(1 + CV_r^2)$

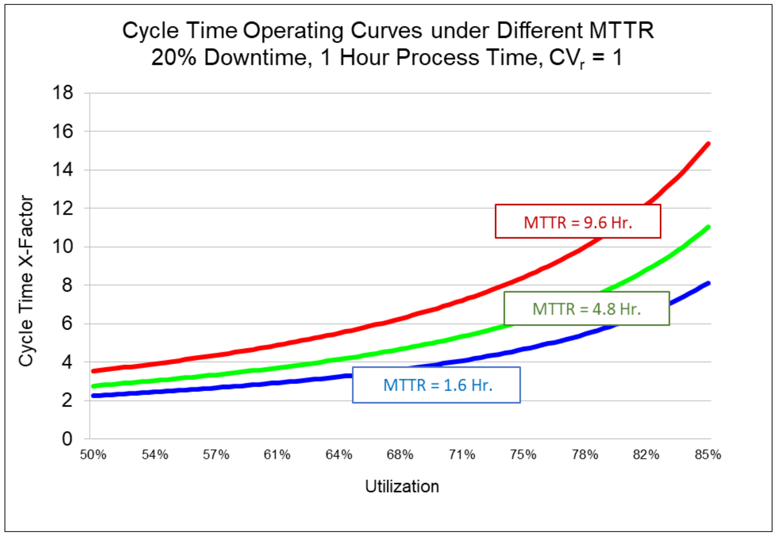
Where CV_r is the coefficient of variation of the repair time and Availability = 1 – Percent Downtime.

Availability: Let's look first at availability. If availability is perfect (100%), then the first term becomes zero, and the entire Downtime Variability term is zeroed out. Otherwise, the first term is maximized (i.e., has the most impact) if availability is 50%. Then [Availability*(1 – Availability)] = .5*.5 = .25. The availability value thus has a relatively low impact here, though of course overall availability has a major impact on the utilization effect of downtime, as described above.

What's clear when we look at this formula is that both MTTR and CV_r can have a significant impact on cycle time.

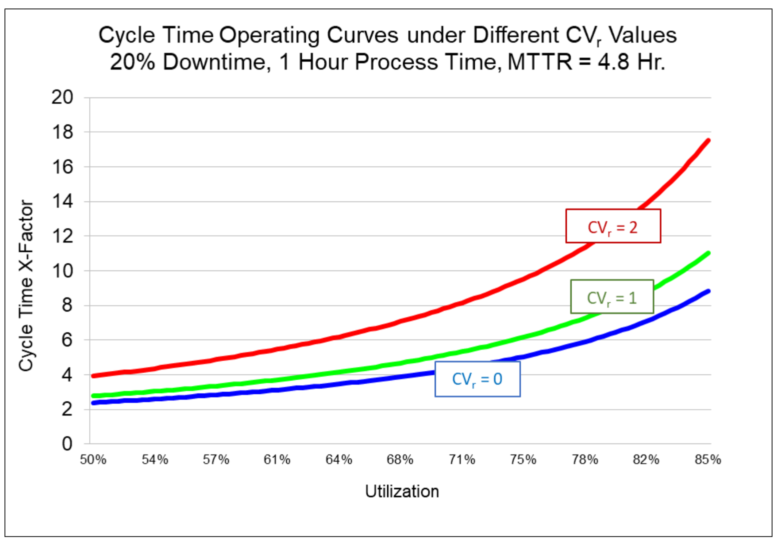
Repair Time Duration: Let's look at the middle term of the downtime variability equation: **MTTR/Average Process Time**. The longer the repair time (MTTR), the greater the impact on cycle time. This reflects what people see in the fab. It's the long downtimes that really hurt productivity. Large amounts of WIP pile up, and it can take a long time to recover from these occurrences. This is especially a problem for one-of-a-kind tools, but applies to tool groups with multiple tools, too. The impact is particularly significant for tools with short process times, because more lots are impacted by the downtime.

An example from the Operating Curve Spreadsheet is shown to the right, where MTTR varies, while the total percentage downtime is held constant. For the same total amount of downtime, a longer, less frequent repair time has a much more negative impact on the operating curve than a shorter, more frequent repair time. See Issue 22.01 for a discussion of the implications of this behavior on PM scheduling.



Repair Time Variability:
Let's look at the last term from the Downtime Variability equation: **$(1 + CV_r^2)$**. When the coefficient of variation of the repair time is zero, that means that the repair always takes the same amount of time. This is the best case for variability reduction and hence, for cycle time. Anything greater than zero drives up the impact. And because CV_r is squared, the impact becomes particularly large when CV_r is greater than one. This reflects what we see in the fab – when repair times are highly variable, this means that some of them are long. And again, those long repair times are the ones that have the most significant impact on cycle time.

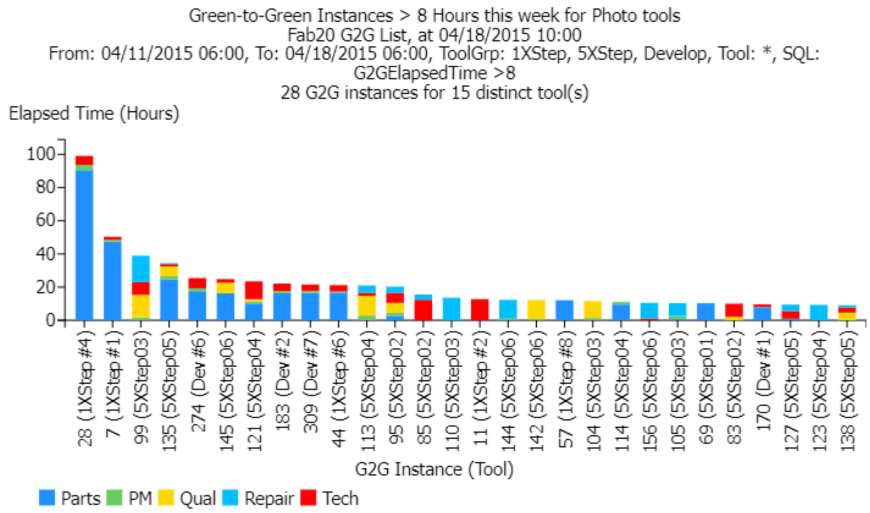
Looking at another example using the Operating Curve Spreadsheet, again with 20% downtime, consider varying the coefficient of variation of the repair time (where the average repair duration is 4.8 hours). The blue line shows constant repair times, while the green and especially the red show greater repair time variability. Because CV_r is squared in the formulas, the red line looks especially bad. This high level of variability can be realistic, however, when we consider something like a possible three-day downtime while the maintenance team waits for a part to arrive from the equipment supplier.



What does this mean in terms of metrics that capture the impact of downtime on variability?
Equipment engineers should track the average duration of unavailable time (MTTR), broken out into scheduled vs. unscheduled downtime. They should also keep an eye on the maximum repair times and strive always to reduce those. Tracking each period of unscheduled downtime according to how the time was spent (e.g. waiting for a technician vs. waiting for parts) is also useful here. This information, aggregated across like tools, can give insight into needed training for maintenance teams, which spare parts contracts are worth investing in, etc.

Green-to-green time (G2G) is also a useful metric here. G2G measures the total elapsed time between two good states (standby or productive), grouping together scheduled and unscheduled downtime, qual time, etc., as shown to the right. The idea is to look at the total time that the tool is unavailable to manufacturing, because this is the factor that most directly drives up cycle time. See Issue 20.02, A Metric for Green-to-Green (G2G) Analysis, for more details.

Green-to-green charts can group consecutive down intervals into one instance, capturing the full impact of the downtime



Equipment engineers should track the coefficient of variation of both scheduled and unscheduled downtime events by tool group and strive to reduce those. Note that the CV can be reduced in part by focusing on bringing in outliers in the MTTR, as described above. It may also be useful to track the CV of Green-to-Green instances for a tool group, and try to reduce that. MTTR, G2G, hours of unscheduled downtime by sub-state, and CV_r for scheduled and unscheduled downtime are all standard charts in the FabTime reporting engine.

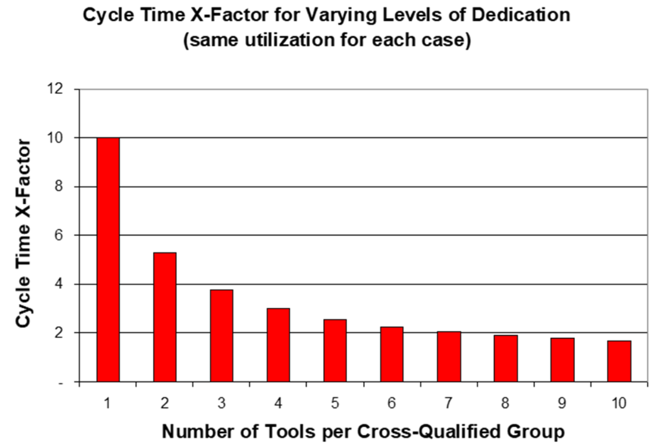
What about Mean Time Between Failures (MTBF)?

What we've seen in this section is that average downtime duration as well as the variability of the downtime duration have a significant (and distinct) impact on equipment cycle time. **Increasing mean time between failures, on the other hand, won't improve cycle time, except as it drives overall availability, and can sometimes be counterproductive**. For the same downtime duration, sure, it's better if the tool goes down less frequently. But, it's also better to bring the tool down regularly for maintenance than to risk a long unscheduled downtime. And it's better to bring the tool back up right away after a downtime to work off the WIP that has accumulated, even if it means bringing the tool down sooner for the next PM (vs. doing the PM while the tool is already down).

Downtime makes the number of qualified tools more variable

The third fundamental driver of cycle time at the tool group level is the number of qualified tools. See Issue 20.05: The Impact of Tool Qualification on Cycle Time for more details. The number of qualified tools for a given recipe has a significant impact on cycle time, particularly as we go from one qualified tool to two. There's about a 50% reduction in cycle time when going from one tool to two (at the same utilization for each tool), with about another 25% reduction achieved in going to three qualified tools, and effects diminishing beyond that, as shown in the figure at the top of the next page.

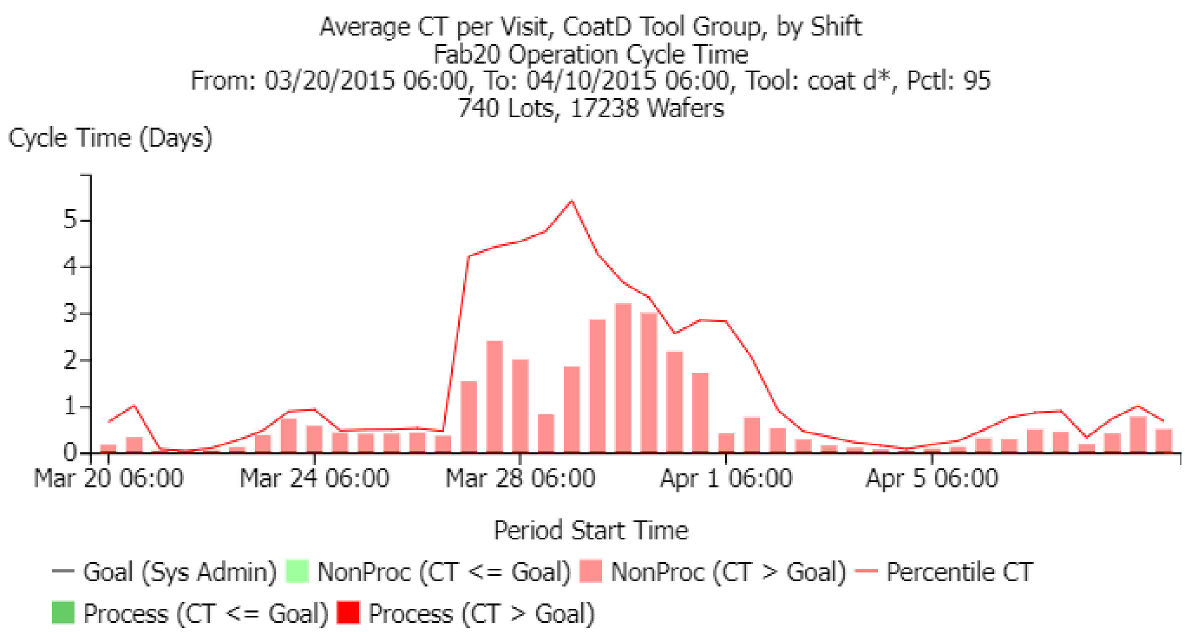
This behavior occurs in the presence of any type of variability and is not specific to equipment downtime. However, it's easy to see that downtime reduces the number of qualified tools that are available at any given time. Sometimes, downtime reduces the number of available qualified tools to zero, which is the worst case for cycle time.



The impact of downtime on number of qualified tools is captured, at least indirectly, by tracking the coefficient of variation of the availability of each tool. Consider the sequence of availability values recorded for each shift for a tool over a one-month period. The best case for cycle time is, of course, for that sequence to consist of all values of 100%. But if the average availability of the tool is, say, 90%, then the best case for cycle time is for each tool to be available for 90% of each shift, day in and day out, down for only 1.2 hours out of the 12-hour shift. (Barring very long qual times, at least.)

The worst case for cycle time is for the availability to sometimes be 100%, but sometimes be 0% (down for the whole shift, or, even worse, for days at a time). This is also the sequence that will give us the highest coefficient of variation. Remember, CV measures how widely things are dispersed from an average.

What happens when we have individual tools with a high CV of availability is that we have a higher likelihood of having multiple tools unavailable at the same time, and thus of having lots arrive to find no qualified tools available, or to find only one qualified tool available when there should have been redundancy. That's what's happening in the chart below, which shows a spike in per visit cycle time for a tool group that theoretically has four qualified tools, but also has high availability variability.



The average availability for each CoatD tool over a three-week period is 60% and the average utilization of available time is 81.4%. The CV of availability for each tool in the tool group over the three-week period (measuring availability by 12-hour shifts) ranges from 0.58 to 0.67.

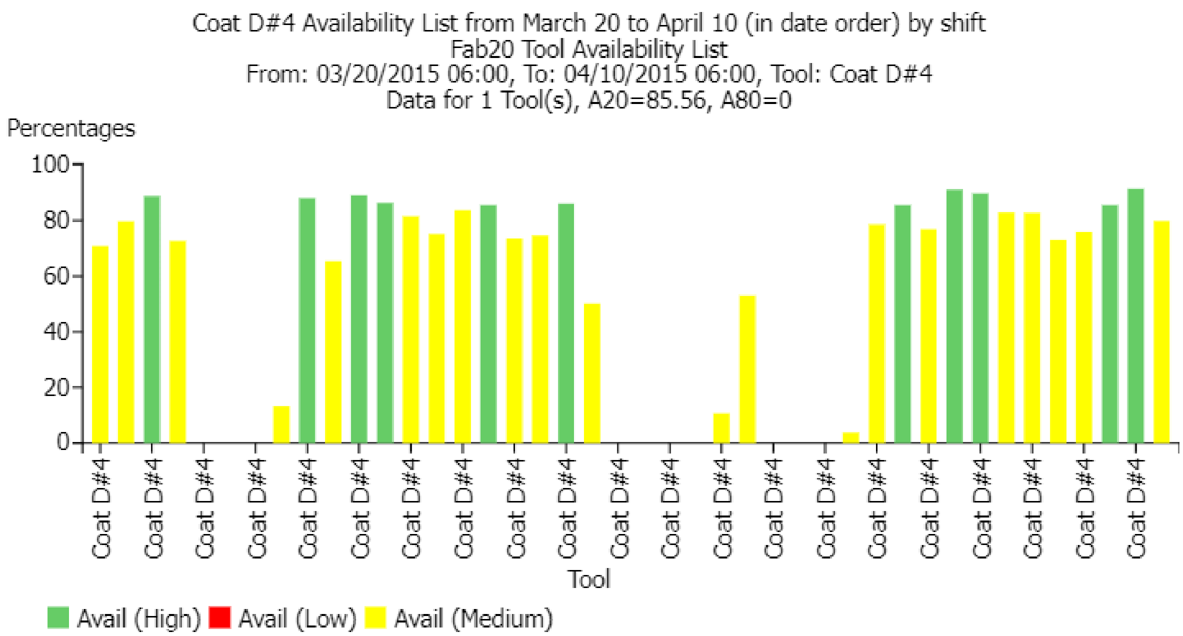
When we look at the average cycle time per visit through this tool group in the chart on the previous page, we see that it is highly variable. Note the period between March 29th and April 1st, when the per visit cycle time reaches as high as 3.2 days, relative to a process time of only 1.3 hours. The x-factor is 58 for the worst shift.

One reason that the cycle time is so high during that period is that two of the four tools in the group were completely unavailable for two full days at the same time. An example of the availability by shift of one of the four tools is shown on the next page. The missing bars are shifts with zero availability.

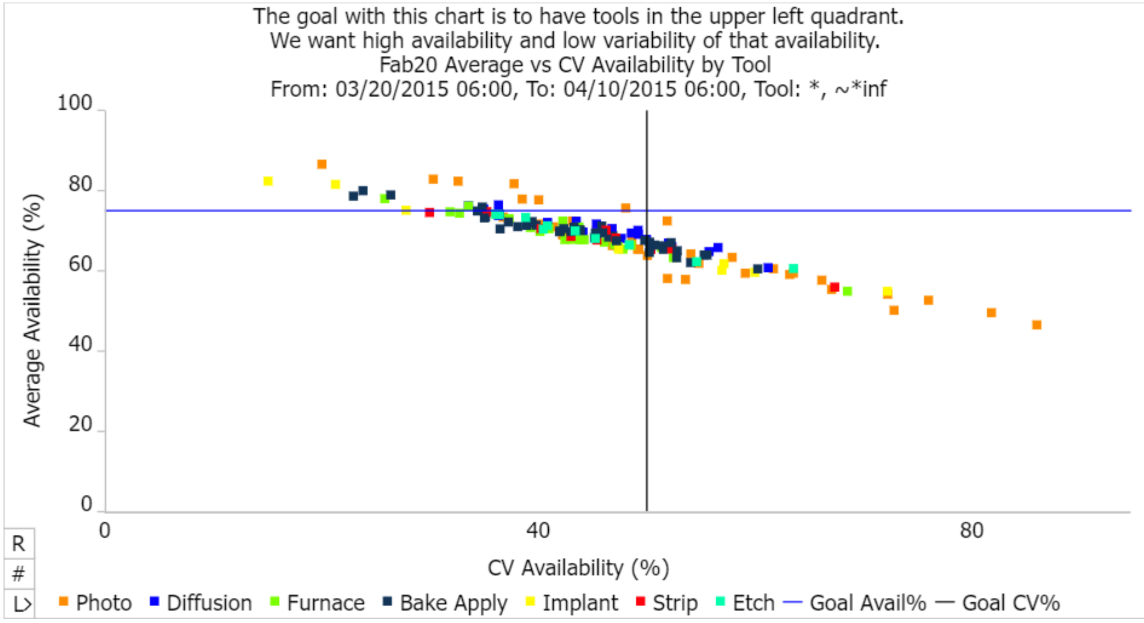
What we want when we look at availability by shift is for the values to be consistently high, not sometimes high, but often zero. When availability is highly variable, our chances of having too few tools available to process incoming WIP are high.

What does this mean in terms of metrics that capture the impact of downtime on number of qualified tools?

Equipment engineers should track the coefficient of variation of availability for each tool by recording availability per shift (or per day), and then calculating CV as standard deviation / average of those values. For instance, the CV of the availability values in the chart at the top of the next page is 0.67.



A useful chart that we include in FabTime shows Average vs. CV of Availability by tool as a quadrant chart. An example is shown below. Each dot represents an individual tool, and the tools are colored according to their area in the fab. In this example, the worst-performing tools are the ones in the lower right-hand quadrant. These tools have poor availability and highly variable availability. We can never count on having the tool be up and running. The tools in the lower right-hand quadrant should be the focus of equipment reliability improvement efforts.



Another metric that focuses on availability variability is A20/A80. A20/A80 generates the sequence of availability values by day or shift (as shown in the Coat D#4 Availability List above) and identifies the availability achieved in the best 20% of the shifts and the best 80% of the shifts. When those values are close together, that means that the availability is consistent from shift to shift. See Issue 18.04: Measuring Variability of Availability for more information.

In summary, what metrics should we use to capture and communicate the attributes of downtime that truly impact cycle time?

What we've shown in the above sections is that overall availability, average duration of downtime, variability of the downtime duration, and variability of overall availability all directly impact the cycle time through a given tool group. These are the attributes that we should be tracking within the fab and using to communicate between equipment suppliers and fab maintenance teams. Metrics to use for this include:

- **Overall availability by tool group**, which helps increase standby time, providing a buffer against high utilization.
- **Average duration of unavailable time**, measured as mean time to repair (MTTR) for scheduled and unscheduled downtime and/or average length of green-to-green time instances.
- **Maximum duration of MTTR** and/or green-to-green time.
- **Average number of hours spent in downtime substates** by tool type, which helps identify opportunities for cross-training and justifying spare parts.
- **Repair time variability**, measured as CV_r for both scheduled and unscheduled downtimes (and potentially for green-to-green instances).
- **Availability variability**, measured as CV of the sequence of availability instances by tool, either by day or by shift, and/or A20/A80.

What shouldn't we do?

- Rely on MTBF (mean time between failures) at the possible expense of MTTR. That is, avoiding maintenance events to keep the tool up and running for longer, at the potential risk of a lengthy unscheduled downtime, is a bad idea.
- Group PMs, unless by doing so we significantly reduce the total time that the tool is unavailable. For the same amount of unavailable time, it's better to have the tool down for shorter periods, so any WIP that builds up during the unavailable time can be worked off.
- Focus heavily on OEE for tools that are not highly utilized. These tools by definition will have operational efficiency losses, and thus have low OEE. Looking at OEE loss factors is still helpful for non-bottleneck tools, but it should be noted that only availability efficiency is directly under the control of the maintenance team.

Conclusion: selecting the right metrics for tracking downtime can help with cycle time improvement as well as communication between fab personnel and equipment suppliers

When asked about cycle time challenges in their fabs, many people cite equipment downtime as the top contributor. Downtime impacts cycle time by taking away buffer capacity (driving tools to a steeper part of the operating curve), increasing effective process time variability (because lots must wait during downtime events), and reducing the available number of qualified tools during a given day or shift.

The four core attributes of downtime that drive cycle time are overall availability, repair time duration, repair time variability, and availability variability. These in turn suggest specific metrics that are helpful for driving cycle time improvement, and others that are less useful. These metrics, of course, are all available in the FabTime reporting module.

Closing Questions for Newsletter Subscribers

What metrics do you use to track equipment reliability? Do you track the variability of availability, in addition to the average availability value?

Further Reading

J. Robinson and F. Chance, "Fundamental Drivers of Wafer Fab Cycle Time," *FabTime Newsletter*, Vol. 22, No. 4, 2021.

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

J. Robinson and F. Chance, "Measuring Variability of Availability, *FabTime Newsletter*, Vol. 18, No. 4, 2017.

J. Robinson and F. Chance, "A Metric for Green-to-Green (G2G) Analysis," *FabTime Newsletter*, Vol. 20, No. 2, 2019.

J. Robinson and F. Chance, "On Breaking Up PMs and Other Unavailable Periods," *FabTime Newsletter*, Vol. 22, No. 1, 2021.

SEMI E10 Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM). Available for purchase from the SEMI store.

SEMI E79 - Specification for Definition and Measurement of Equipment Productivity. Available for purchase from the SEMI store. (Includes OEE.)

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