Maximize Your Manufacturing Efficiency: Gain Insight into the Three Fundamental Drivers of Fab Cycle Time

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Why is cycle time improvement worthwhile?

Cost/revenue drivers include:

Reducing Time to Market

- Cutting cycle time gets customer qual lots out the door faster.
- Cutting cycle time provides more R&D cycles of learning.

Increasing Fab Utilization

- Cutting cycle time allows you to run closer to full capacity.

Cutting Costs

- Cutting cycle time may reduce scrap and rework.
- Cutting cycle time decreases WIP and carrying cost.
- Cutting cycle time decreases obsolete inventory risk.

What other reasons are there to improve CT?

Other reasons to improve cycle time include…

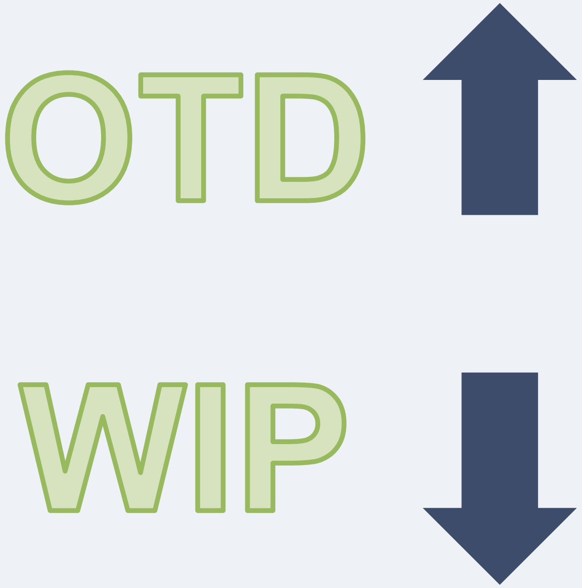
Happier customers

- Shorter cycle times are usually also more predictable cycle times, resulting in better on-time delivery performance.

Happier managers

- A leaner fab with less WIP is more flexible and ready for market changes.
- A fab carrying less WIP is easier to manage in general.

Anyone or anything else?



So, why don't all fabs have great cycle time?

Why are CTs high? Short answer: cost, complexity, and change

- Wafer fab equipment is expensive and tends to be highly loaded.
- Wafer fab process flows are long and complex.
- Product and technology mix change rapidly (so we don't qualify new recipes on tools, and the tools can be unreliable).
- And lots more that we'll discuss…

What specific factors in the fab do you think contribute to high CT?

Other challenges keeping fabs from getting great CT include…

- Downtime (scheduled and unscheduled)
- Product mix
- Bottlenecks/utilization
- One-of-a-kind tools/single path operations
- Holds
- Setups
- Process variation
- Soft dedication/operator preferences for tools
- Time constraints between process steps
- Lot release

- Operator unavailability
- Scheduling/dispatching
- Engineering use of tools
- Running development lots in a production fab
- Hot lots
- Reentrant flow
- Scrap / Rework
- Manual lot transport between steps (via carts or runners)
- Batch processing

Given these challenges, what should we do to improve fab CT?

How to improve fab cycle time: a three-step process

Fundamentals

- Help your team to understand **where to look for problems and why.**
- Use this webinar and the FabTime CT newsletter.
- A four-hour virtual class is also available.

Data

- Collect and analyze **data to identify current problems** in the fab, highlighting the most important and actionable opportunities.
- INFICON products, including FabTime and the FPS dashboard can help.

Action

- **Act** using fundamentals and actual data from the fab.
- **Implement** control technologies like the INFICON FPS Scheduler.
- **Make improvements** that will help future CT.

The 3 fundamental drivers of CT can help you improve profitability by…

Reducing forced idle time on key tools (allowing increased loading of the fab).

- **Driver 1: Utilization**

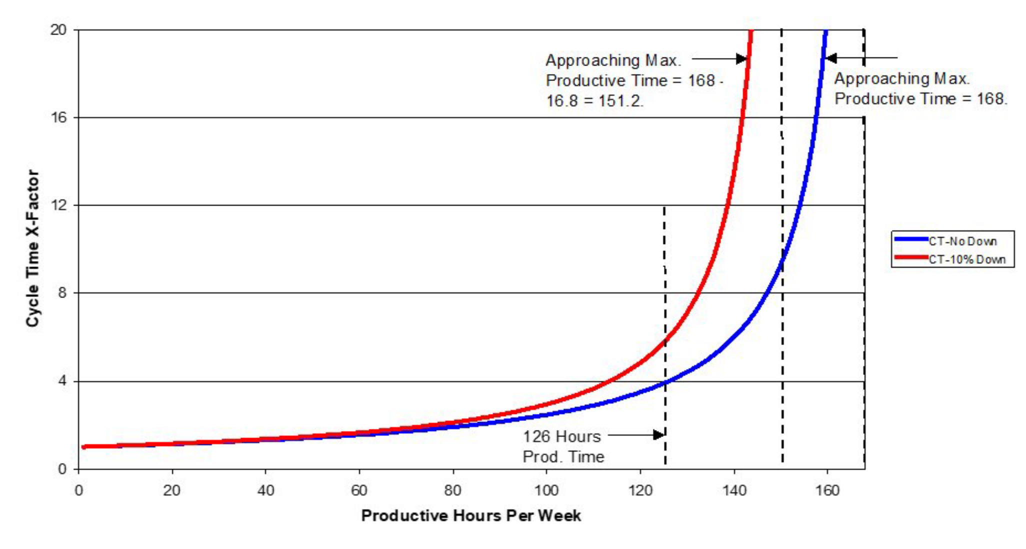
Reducing variability, especially from downtime, and thus allowing fabs to get good cycle time at a higher utilization.

- **Driver 2: Variability**

Improving cycle time of new products by demonstrating where "soft dedication" or insufficient tool qualification is occurring.

- **Driver 3: Number of Qualified Tools**

We'll use operating curves to illustrate impacts on CT



These drivers apply at the tool group level, and roll up to impact overall CT.

Cycle Time and Utilization

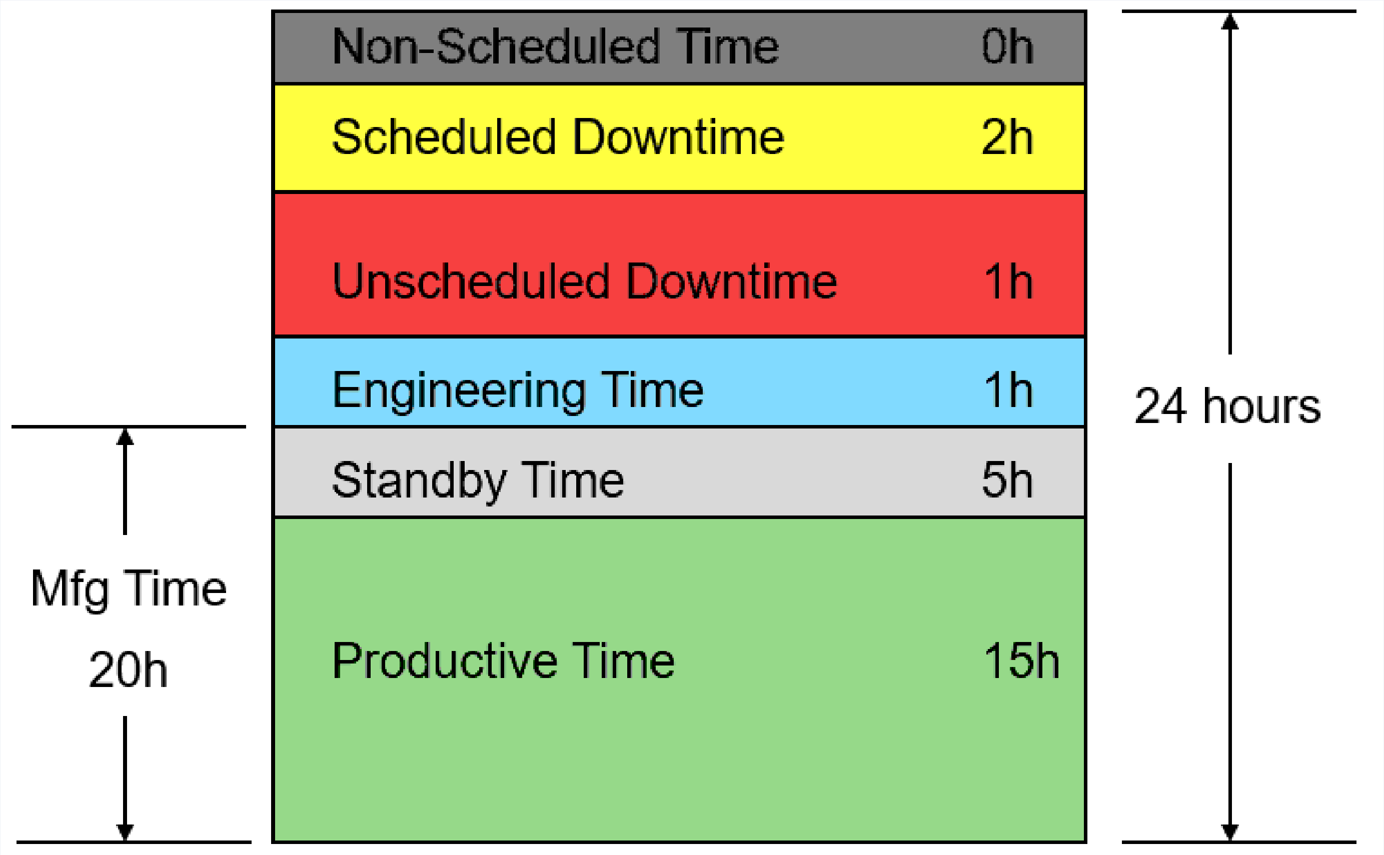
At the tool group level, utilization is the biggest driver of cycle time.

We'll use the SEMI E10 tool state definition of utilization

Utilization = (Productive Time) / (Manufacturing Time)

where Manufacturing Time = Productive + Standby (time the tool is available manufacturing)

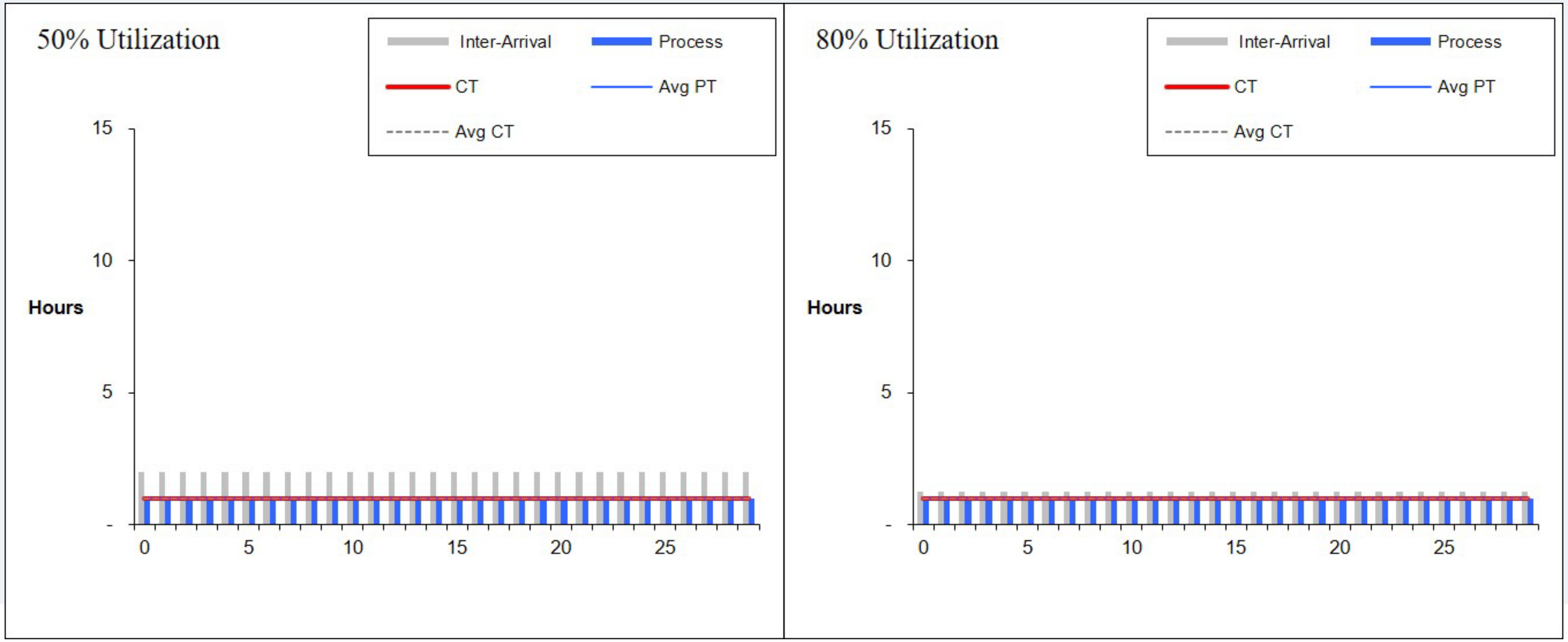
and Productive Time = time spent working on products



Utilization = 15/20
= 75%

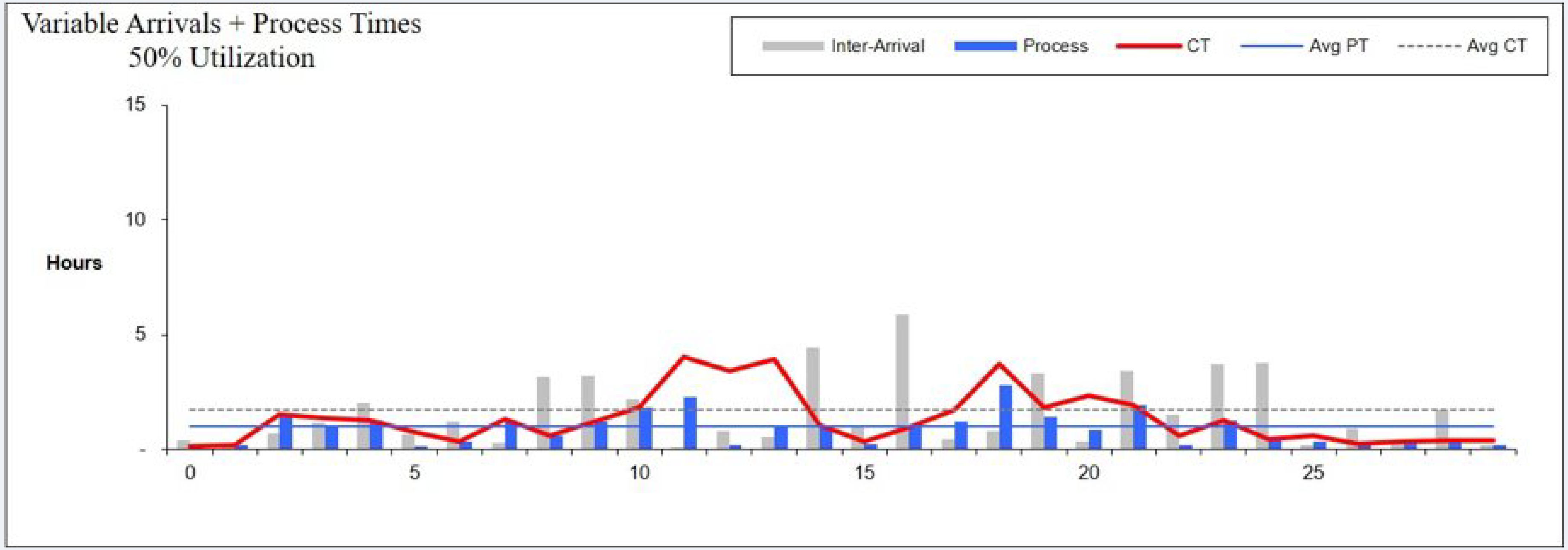
When a tool group has no variability, CT is low regardless of utilization

- Operation CT = Queue Time + Process Time (+ Hold, Travel, etc.)
- Suppose we have a tool where lots arrive at a regular interval (gray bars), with no variability, and process time (blue bars) is always one hour, again with no variability.
- Whether the utilization is 50% or 80% (or anything < 100%), queue time will always equal zero and CT (red line) will always equal the process time.



It's variability that causes lots to wait, and drives up cycle time

- Suppose now average process time is still an hour, but process times and times between arrivals both have moderate variability.
  - Now, we see some queueing even at low utilization (50%).
  - Lots 10 + 11 had longer process times, while Lots 11-13 had short times between arrivals. A small WIP bubble built up. Long arrival times for Lots 14 and 16 allowed catch-up time.

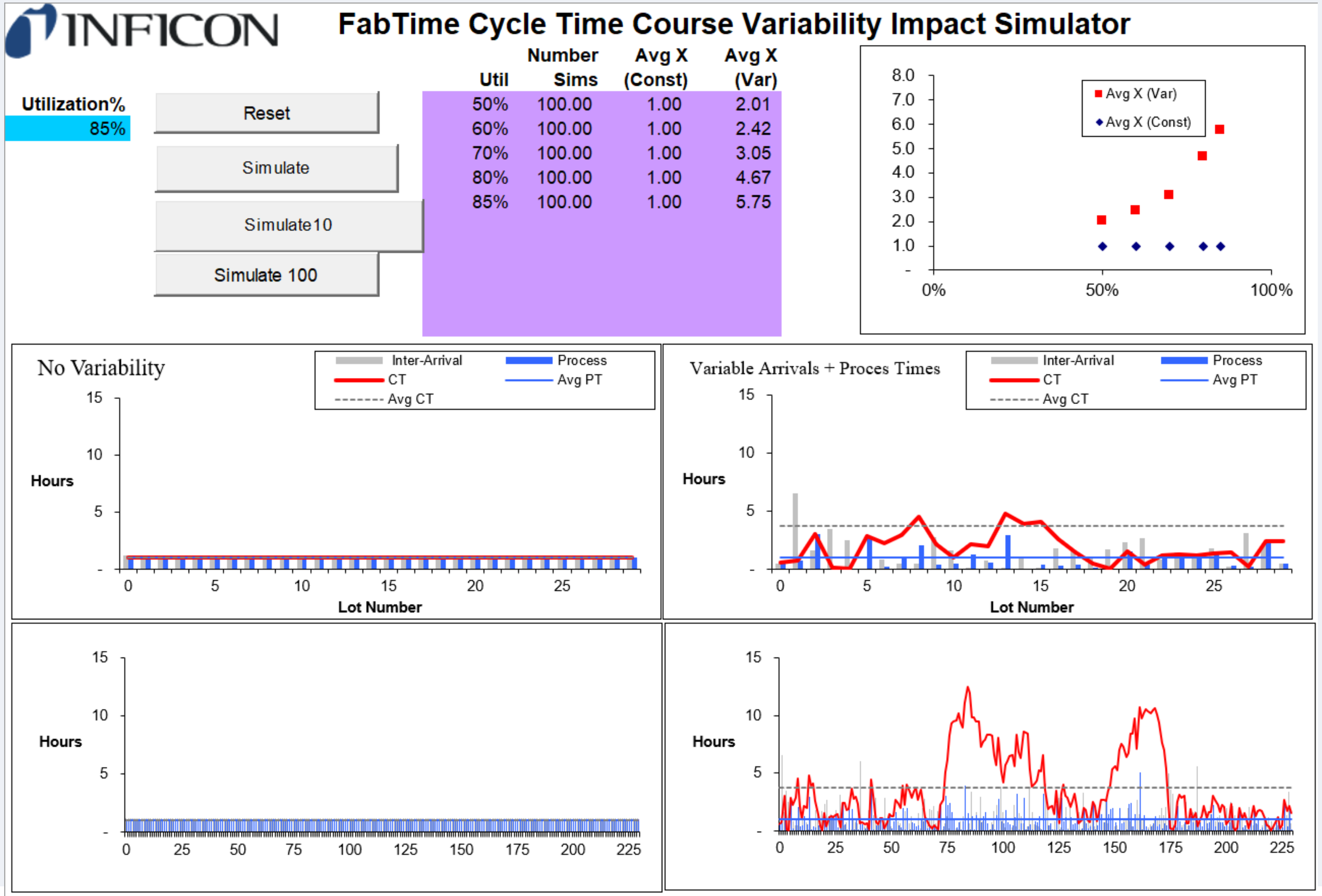


Once there's variability, cycle time increases as utilization increases

At 80% utilization (same avg. process time, less time between arrivals), WIP bubbles are likely to be larger.

- Long process time for Lot 10 is followed by a series of short times between arrivals. Just as CT starts to dip after Lots 23 and 24, Lot 25 has another long process time.
- The double-whammy of more lots to process and less idle time for the tool to recover leads to a non-linear CT increase.

Looking at a range of utilizations, over a longer period (230 arrivals) …



Random numbers are simulated using an Excel spreadsheet tool. Contact Jennifer Robinson for a copy of the spreadsheet.

… We build an operating curve

Operating curve is a graph showing cycle time (or X-Factor, which is CT/Theoretical CT) vs. utilization for a fab or a tool group.

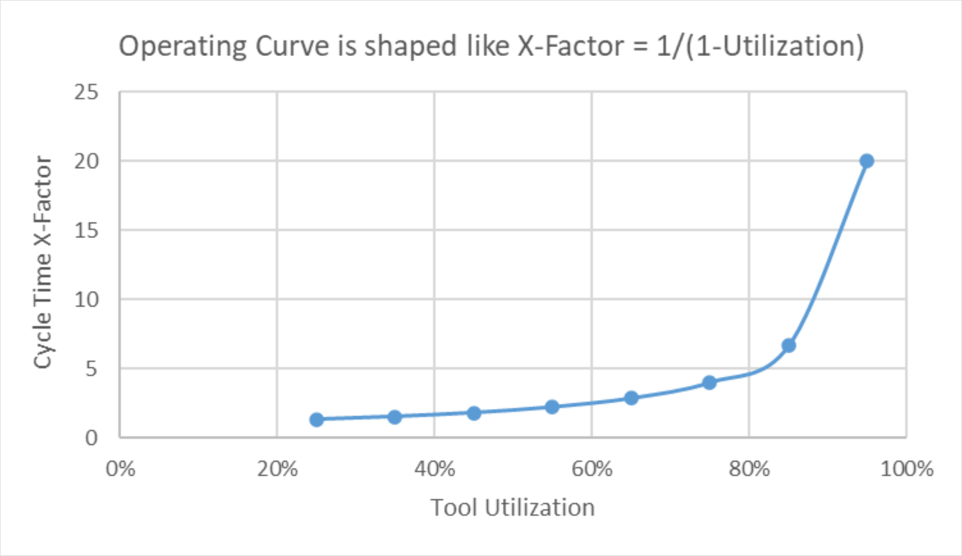
- Usually generated from simulation or mathematical models.
- Can generate from actual data and fit a curve to the data.
- Useful for exploring trade-offs in cycle time goals.
- Another Excel spreadsheet tool (FabTime Operating Curve Generator) uses queueing models to show tool-level behavior.

For a one-of-a-kind tool, the queueing formula is:

X-Factor = 1 / (1 – Utilization)

(This formula is "exact" under certain assumptions.)

Mimics real fabs – once utilization rises above 85%, cycle time starts to increase rapidly. This is sometimes called the "hockey stick effect."



The relationship between CT and utilization creates a Core Conflict for fabs

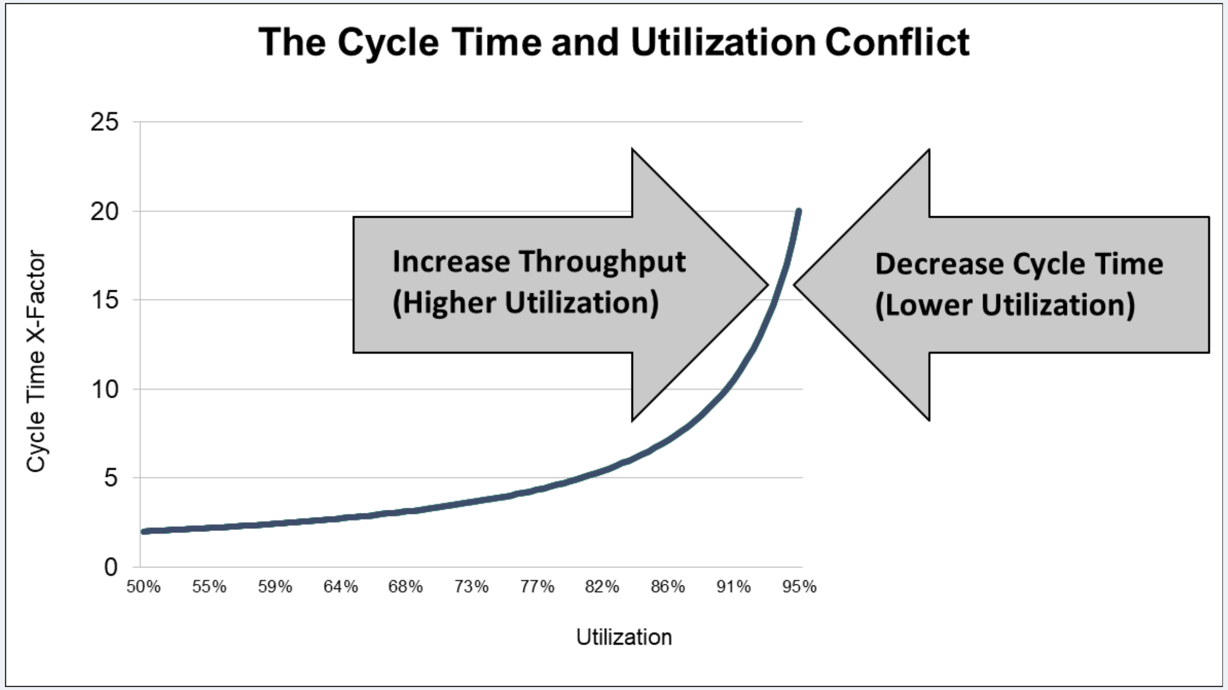
Utilization is the largest driver of CT at the tool level.

To reduce costs, fabs need to increase tool utilization.

To improve CT, fabs need to decrease tool utilization.

- Some standby time is needed on the tools, to keep cycle times reasonable.
- We want to stay away from the steep part of the operating curve.
- The more standby time that can be provided, the better cycle times will be.

How can fabs resolve this conflict?



There are several ways that fabs can resolve the Core Conflict

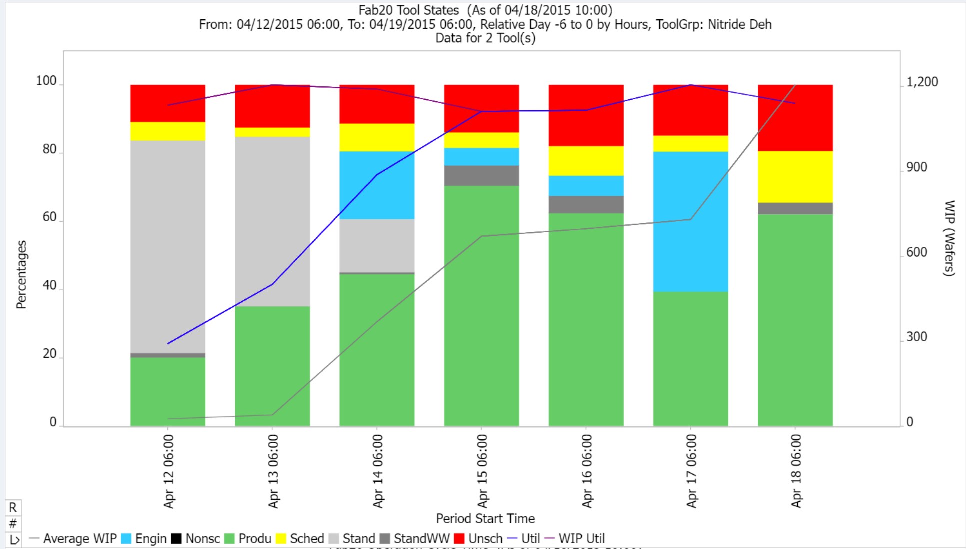
1. Improve **equipment uptime**, thus extracting standby time from current unavailable time.

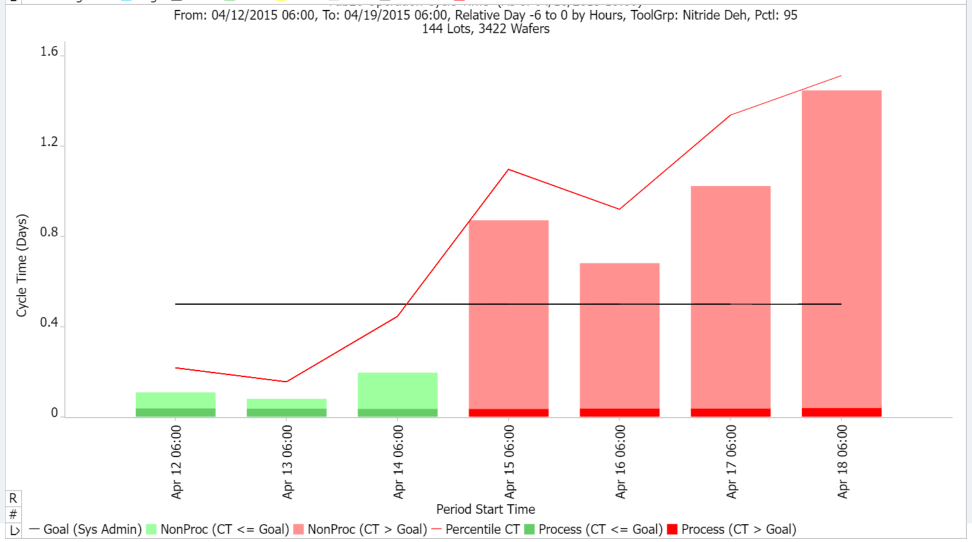
2. Eliminate **forced idle time** (converting wasted time, recorded as standby-WIP-waiting time, into true standby time).

3. Reduce **process times**, so that less productive time is needed for the same number of wafers.

4. Reduce **fab variability**. The impact of this will be shown in the next section.

But first, let's talk more about forced idle time.





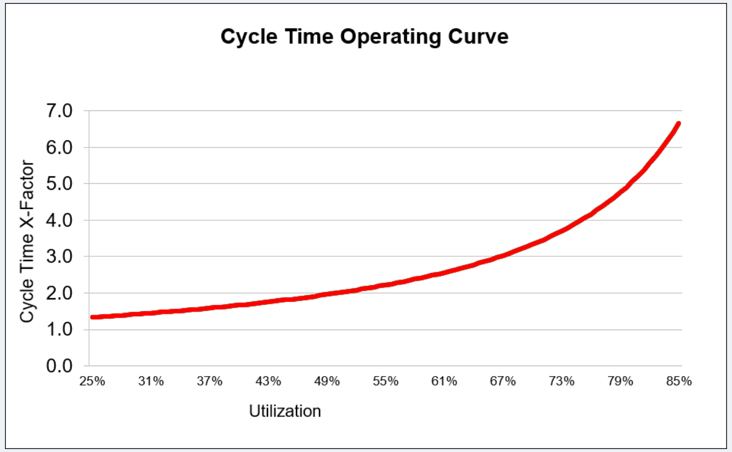
Food for Thought: Which is the biggest source of forced idle time in your fab?

- Operator Unavailability
- Holding Tools for Hot Lots
- Dispatching
- Lot Transport
- Something else…

How can fabs reduce forced idle time to improve productivity?

1. Minimize the number of distinct tools for which each operator is responsible, and stagger break schedules.
   - This is to reduce time that tools spend with WIP, waiting for operators.
2. Reduce the number of hot lots in the fab, especially hand-carry lots that cause setup changes / force idle capacity.
3. Make smart dispatching and scheduling decisions to keep critical downstream tools from starving.
4. Make sure lots aren't sitting on hold when they could be in process.
   - This can happen especially with future holds. Designate a back-up engineer to be alerted for any future hold.

Ideas to keep tools from the steep part of the operating curve



These are covered in more detail in our four-hour CT class.

Cycle Time and Variability

Variability (in arrivals or process times) shifts the operating curve up and to the left. Variability makes it impossible to achieve theoretical cycle time in any real fab

CT increases with variability in both process times and time between arrivals

Contributors to process time variability:

- Different recipes on the same machine / different process times.
- Setups
- Equipment failures
- Rework lots
- Yield loss (scrap)
- Operators
- ...

Contributors to interarrival time variability:

- All the above
- Transfer batching/automated material handling
- Batch processing (multiple lots in a machine at one time)
- Lot release

Which do you think has a greater impact, process time variability or arrival variability?

See FabTime Newsletters 8.04, 16.05

Food for Thought: Which of these is the biggest source of variability in your fab?

- Extended Downtimes
- Hot Lots
- Batch Processing
- Time Links and Rework
- Something else...

We can expand the queueing formula to account for variability

Recall the single-tool X-Factor estimate:

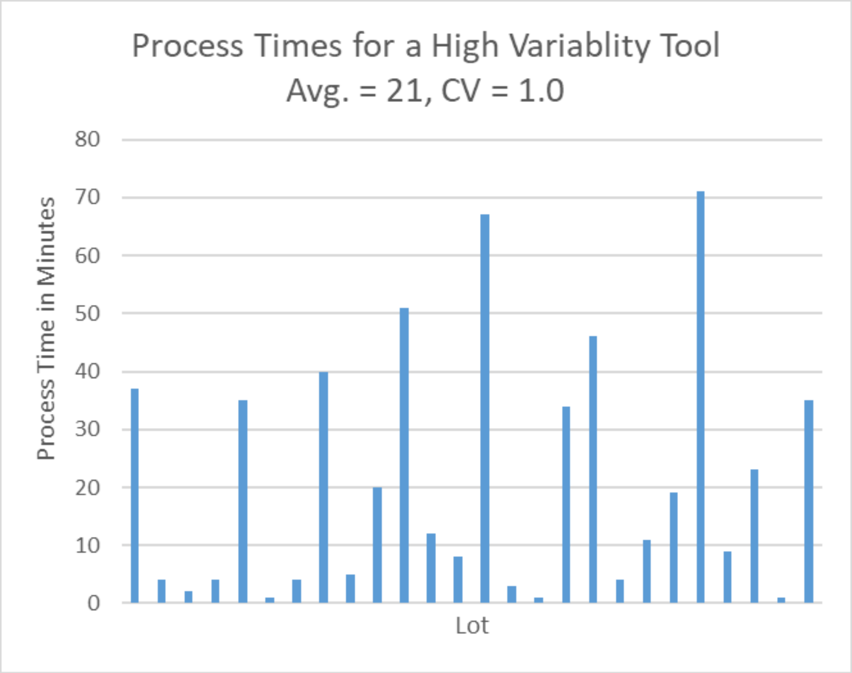
- X-Factor ~= 1 / (1 – Utilization)
- Assumes medium variability in arrivals and process times

More generally (again under certain assumptions)

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

Variability Factor

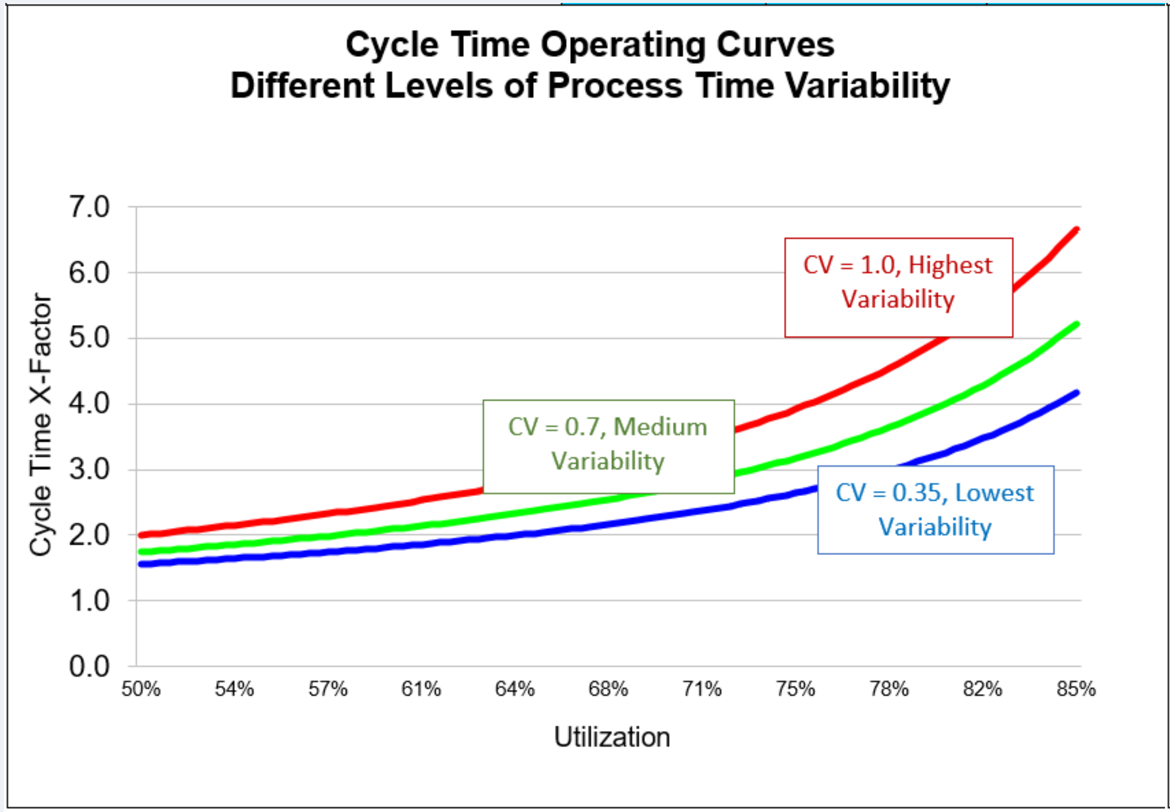
- Sum of arrival variability + process time variability
- Factor = $(CV_a^2 + CV_p^2)/2$
- CV_a = Coefficient of variation for inter-arrival times
- CV_p = Coefficient of variation for process times

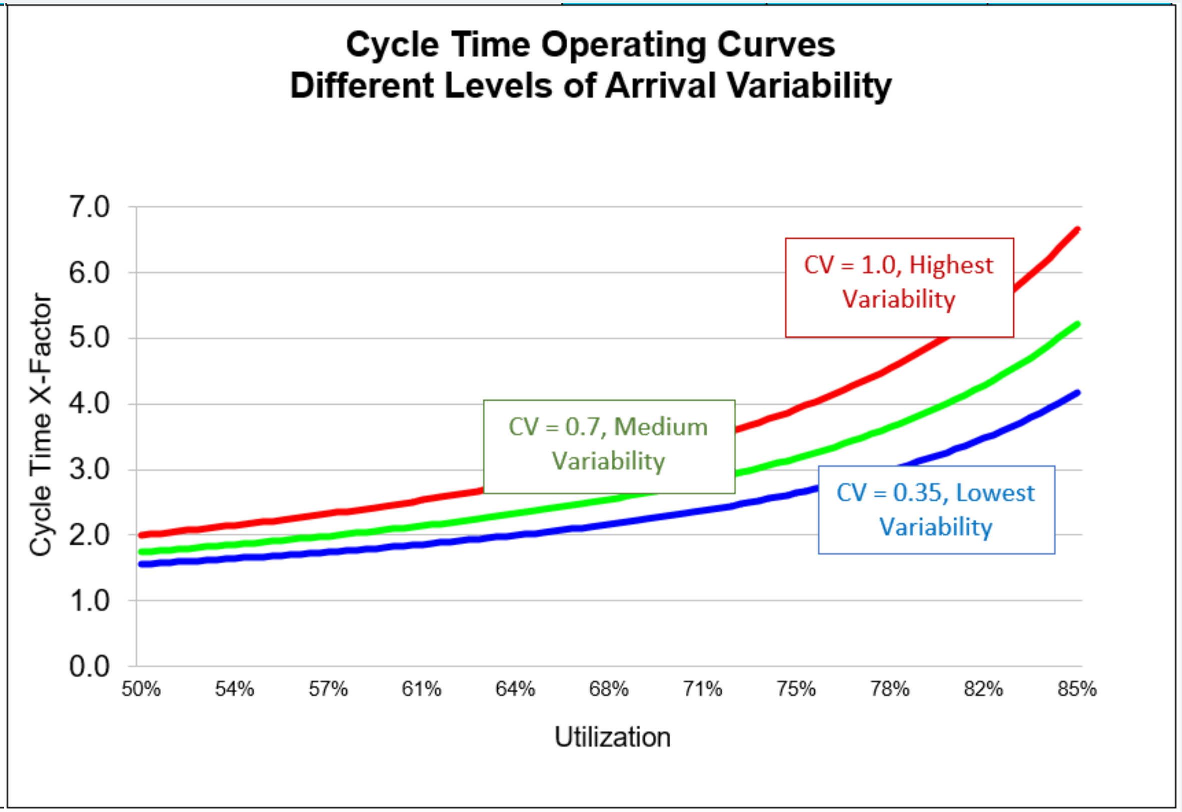


Coefficient of Variation (CV)

- Statistical measure: (Standard deviation) / (Average)
- Standard deviation measures how widely values are dispersed from the average value.

Changing the CV of arrival OR process time variability changes the shape of the curve





So which type of variability has more of an impact?

Variability Factor = $(CV_a^2 + CV_p^2)/2$

With equal amounts of arrival and process time variability, the impact will be equal.

In practice:

- Process time variability will be high on some tools (like implanters) and low on others (like furnaces).
- Arrival variability will be higher in a fab with carts than one with dedicated runners, and higher in a fab with more large batch processes than one with fewer.
- It depends…

What matters is that **you can improve CT by reducing arrival or process time variability**.

- There are many ways to reduce variability in any fab.
- PM scheduling is one way to impact effective process time variability (and downstream arrival variability).

Food for Thought: Your maintenance team proposes grouping daily PMs into one long weekly PM for efficiency. Should you support the change?

Yes!

No!

Maybe…

Why or why not?

More simply, for the same amount of scheduled downtime, is it better to have short/frequent PMs or long/infrequent PMs?

Should you group your PMs?

Consider the impact of longer vs. shorter PM events on a one-of-a-kind tool

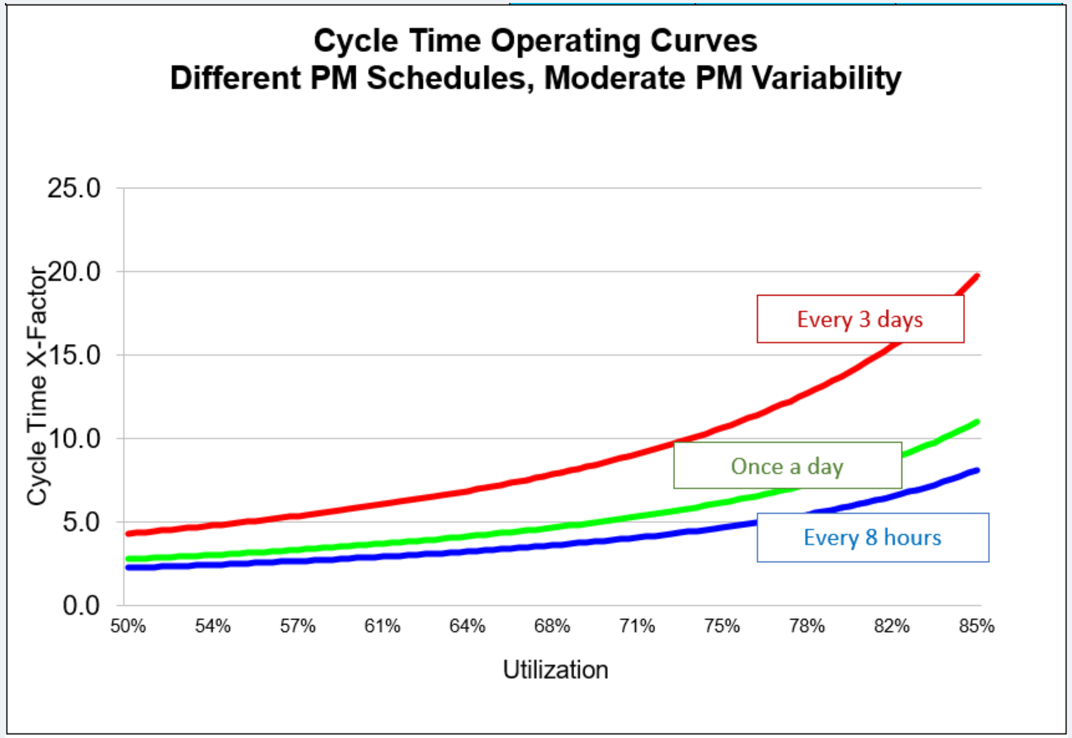
Suppose the tool is down for maintenance 20% of the time under moderate variability.

For the same total amount of scheduled downtime (4.8 hours/day), consider taking the tool down for maintenance:

- Once every 8-hour shift for 1.6 hours
- Once every 24 hours for 4.8 hours
- Once every 3 days for 14.4 hours

The longer period of unavailable time (the upper red curve) is MUCH worse for cycle time.

- We could spend more than 10% of time in extra quals before the red curve would be better than the green.
- The longer PMs also send more variability downstream.



Take home message: for the same amount of unavailable time, avoid grouping PMs for better CT.

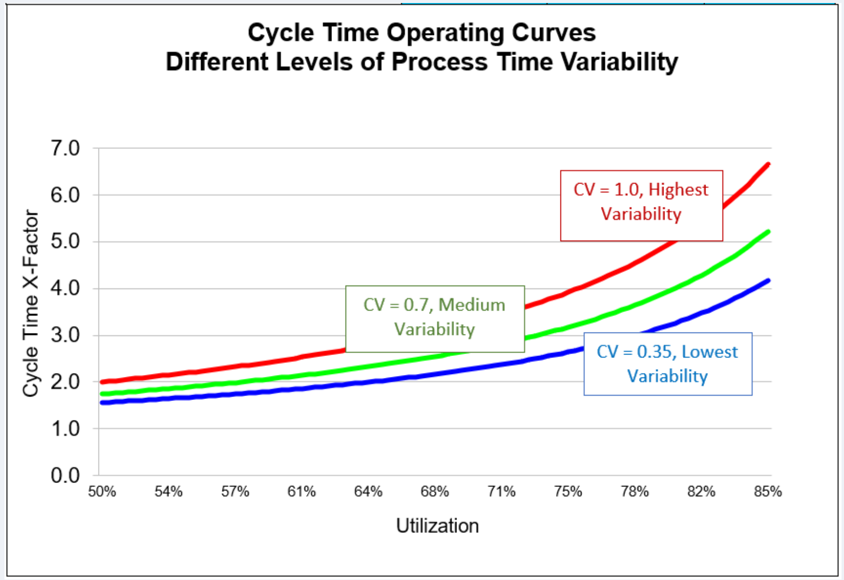
Any type of variability shifts the operating curve up and to the left

Anything that can be done to reduce variability in the fab will shift the operating curve downward and will improve things.

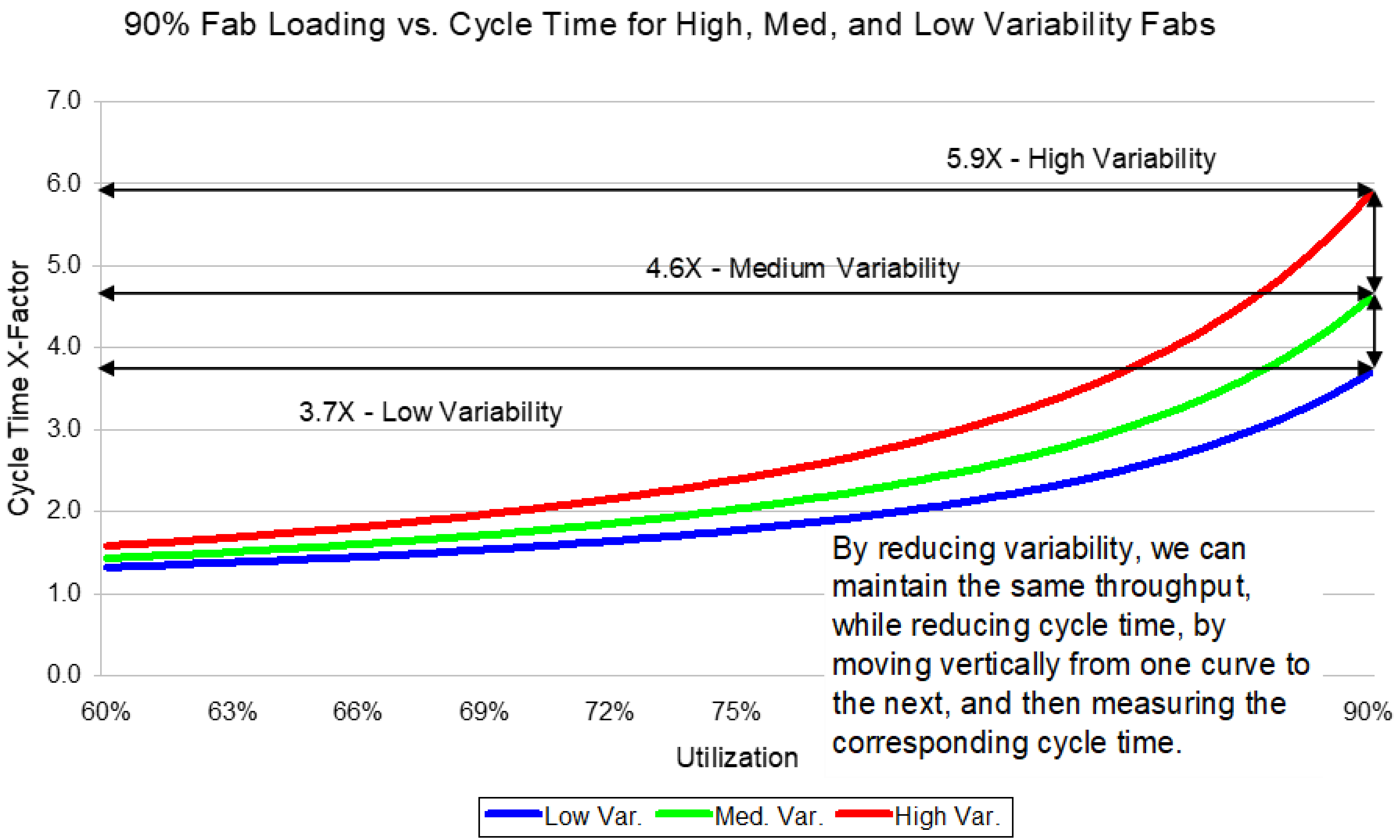
Variability reduction gives the fab a choice:

1. Reduce cycle time, while maintaining the same throughput rate (by moving straight down to a different operating curve).
2. Increase the throughput rate, while maintaining the same cycle time (by moving across horizontally to a different operating curve).

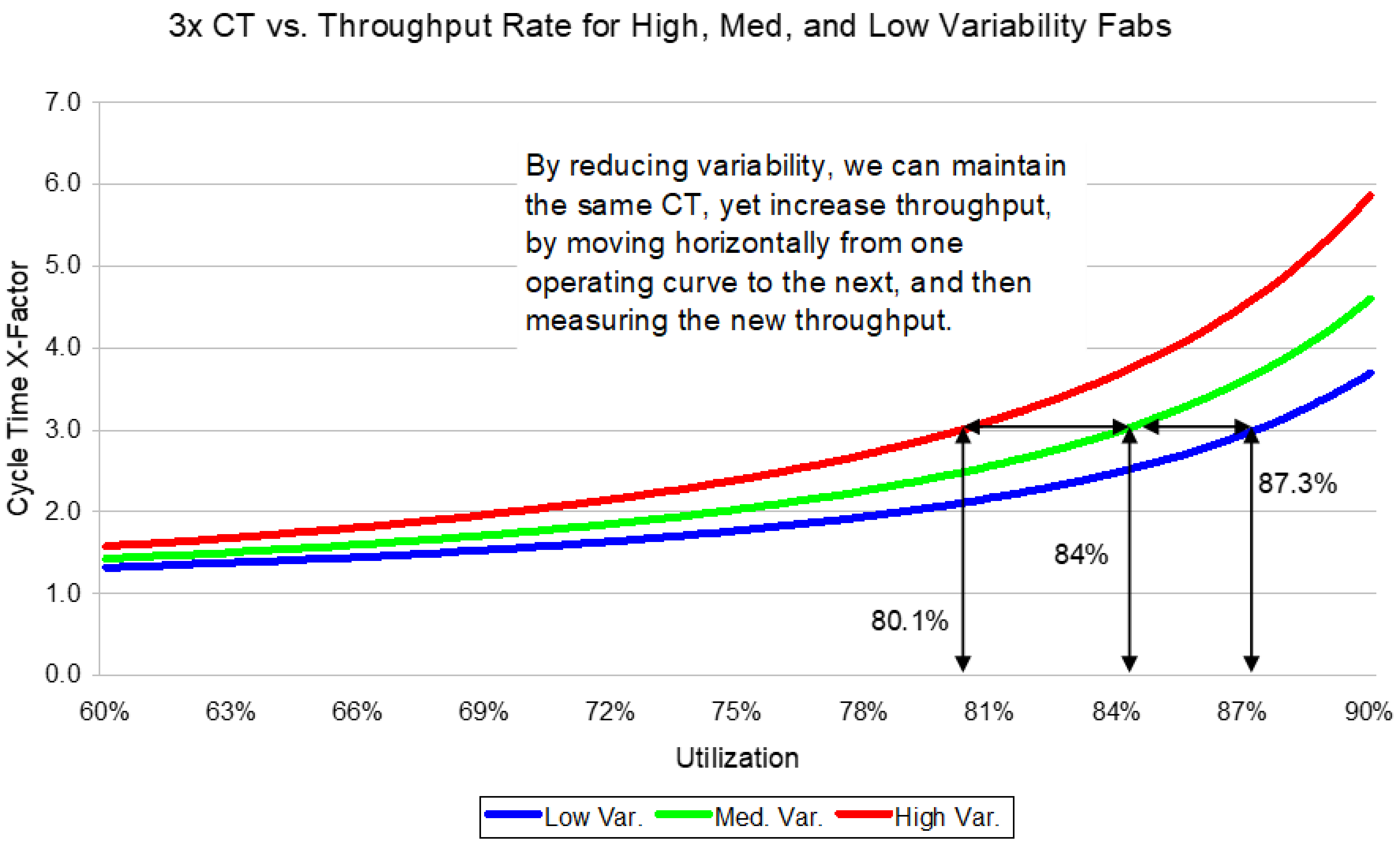
(these are best illustrated graphically)



If we reduce variability, we can get a better CT at the same throughput rate



If we are constrained by a CT target, then reducing CT can increase throughput



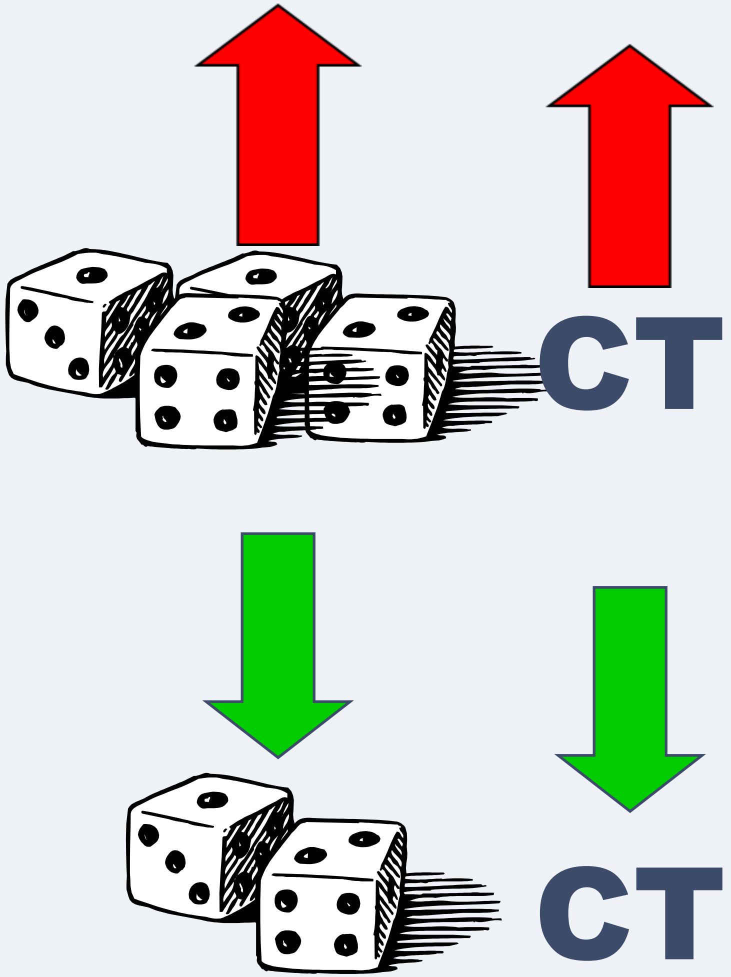
Variability impairs performance for any manufacturing system

Variability is bad!

Decreasing variability in arrivals or process times or from downtime will improve cycle times.

Because you don't have to reduce starts, or purchase additional tools, variability reduction is a relatively inexpensive way to improve cycle time and reduce work in process.

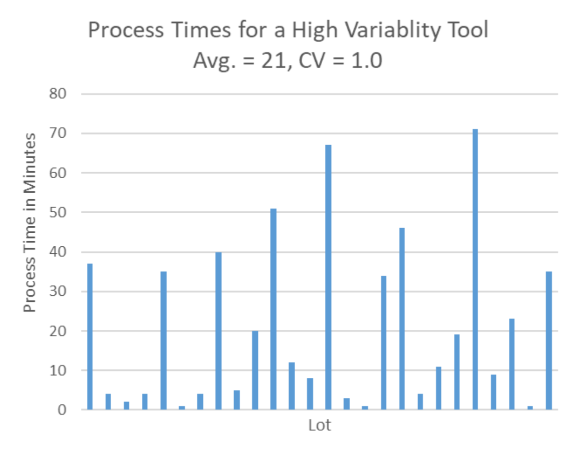
Measure arrival and process time CVs, as well as availability variability, to identify areas for cycle time improvement.

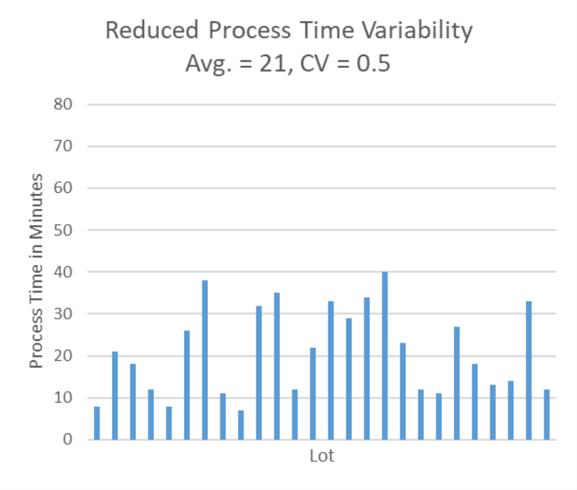


How can fabs reduce variability to improve profitability/performance?

Systematically monitor (using CVs and control charts) and reduce variability:

- In process times.
- In tool availability (or Green-to-Green time).
  - Separate maintenance events instead of grouping them.
  - Ensure sufficient MTs and spare parts.
- In starts (if possible) and between steps (via changes in lot transport and via dispatching and scheduling).





Also:

- Consider greedy policy for lightly loaded batch tools and using smaller carts.
- Reduce setup and rework.
- Reduce the number of hot lots in the fab.

More details about these in our newsletter and 4-hour CT class.

Cycle Time and Number of Qualified Tools

***The number of qualified tools in a tool group has a major impact on cycle time. This impact increases with higher levels of utilization and variability*.**

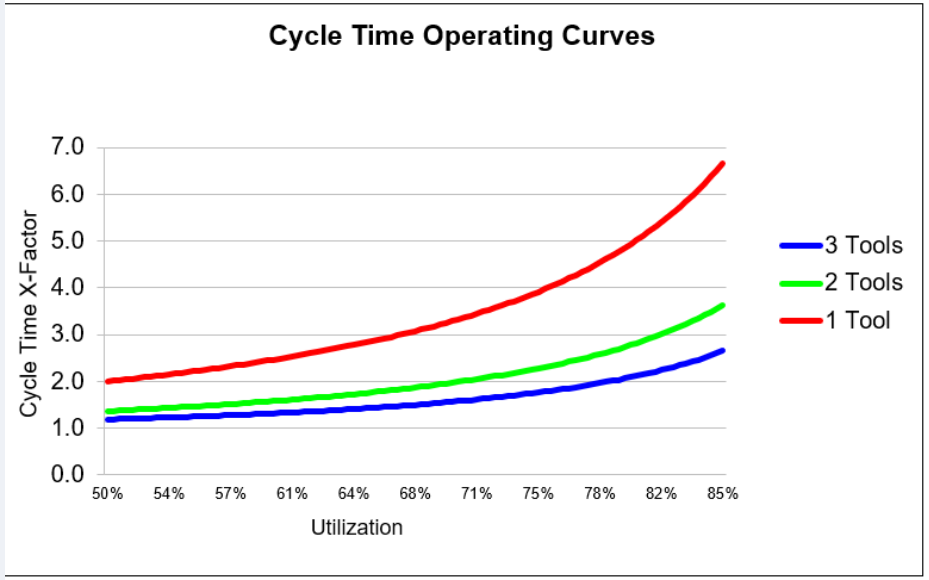
Going from one to two qualified tools cuts CT per visit roughly in half

FabTime Cycle Time Course Operating Curve Generator

INFICON
Inspired by visions. Proven by success.

Calculates regular lot (non-hot-lot) cycle time for multiple-tool machine groups with general arrival and service processes.
Each tool has a single failure process, indicated by MTBF and percentage downtime.

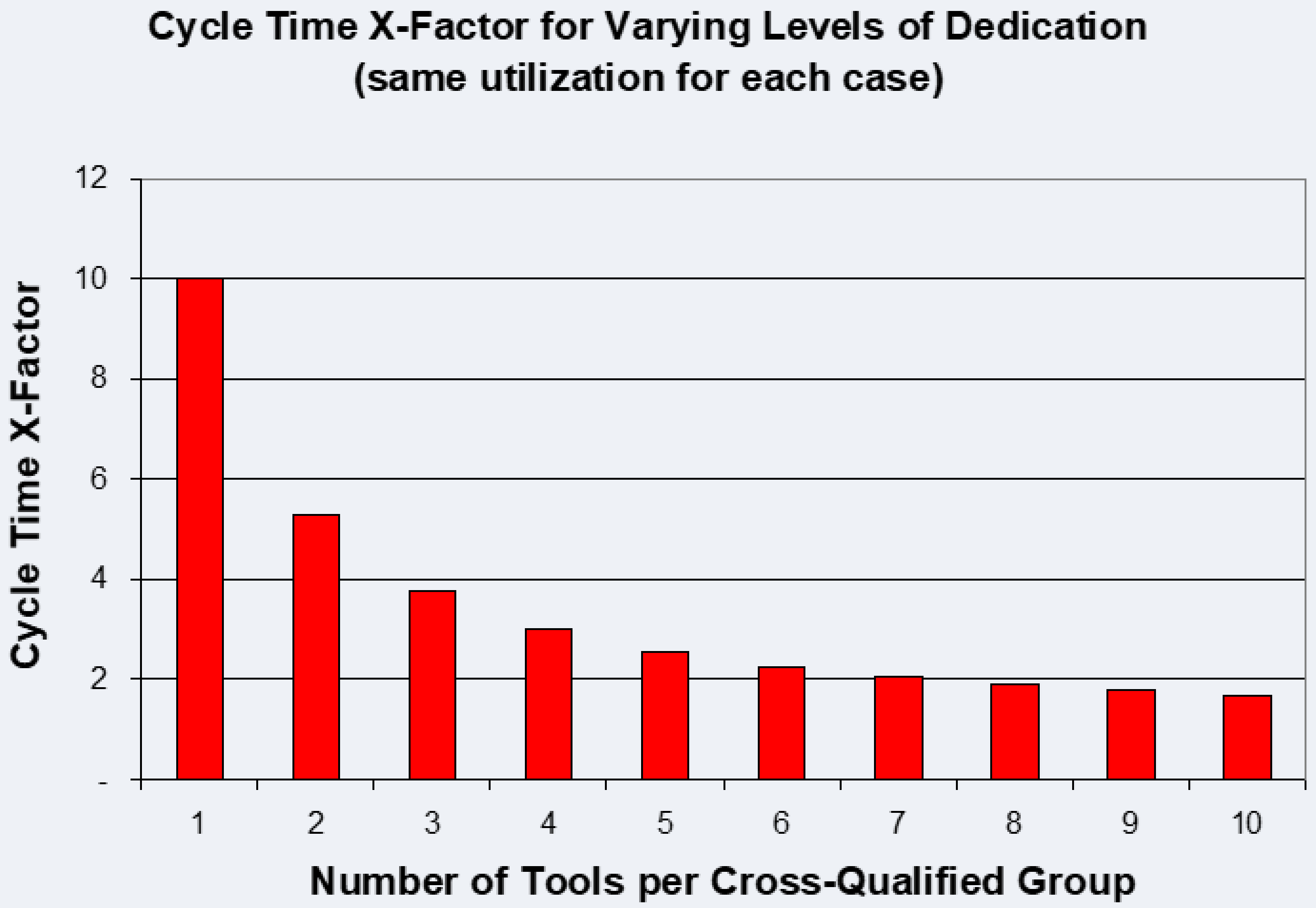
Source	Description	3 Tools	2 Tools	1 Tool	Notes
Operations	Average process time (hours)	1	1	1	
Operations	Hot lot percentage	0%	0%	0%	Percent of WIP with priority over regular lots.
Operations	Number of tools	3	2	1	
Operations	Process time variability	1	1	1	Coefficient of variation of process times
Operations	Inter-batch arrival variability	1	1	1	Coefficient of variation of arrival process
Operations	Average arriving batch size (lots)	1	1	1	If lots tend to arrive in batches
Operations	Arriving batch size variability	0	0	0	Coefficient of variation of arriving batch size
Operations	Repair time variability	1	1	1	Coefficient of variation of repair process
Operations	Mean time between failures (hours)	24	24	24	MTBF
Operations	Percentage downtime	0%	0%	0%	



Left end-point for x-axis (min utilization)	50%
Right end-point for x-axis (max utilization)	85%

FabTimeOperatingCurveGeneratorCourse.xlsx

As we increase the number of qualified tools/recipe, the benefit levels off



Tool group is 90% utilized, level of cross-qualification varies.

The intuitive explanation is that we need a backup in case of variability

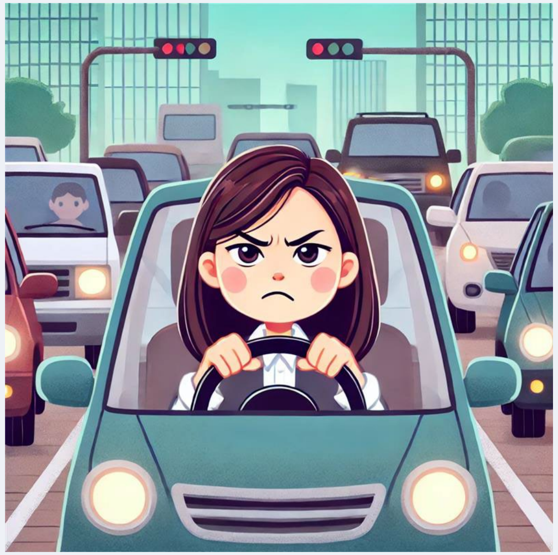
When there's only one tool, a lot is subject to all the variability associated with that tool (long process times, downtimes, etc.).

When there are two tools, the probability of both tools being hit by a long delay at the same time is much smaller. The lot can be processed on the second tool.

- With 3 tools, the probability of all 3 being impacted at the same time is even smaller.

Real-World Examples:

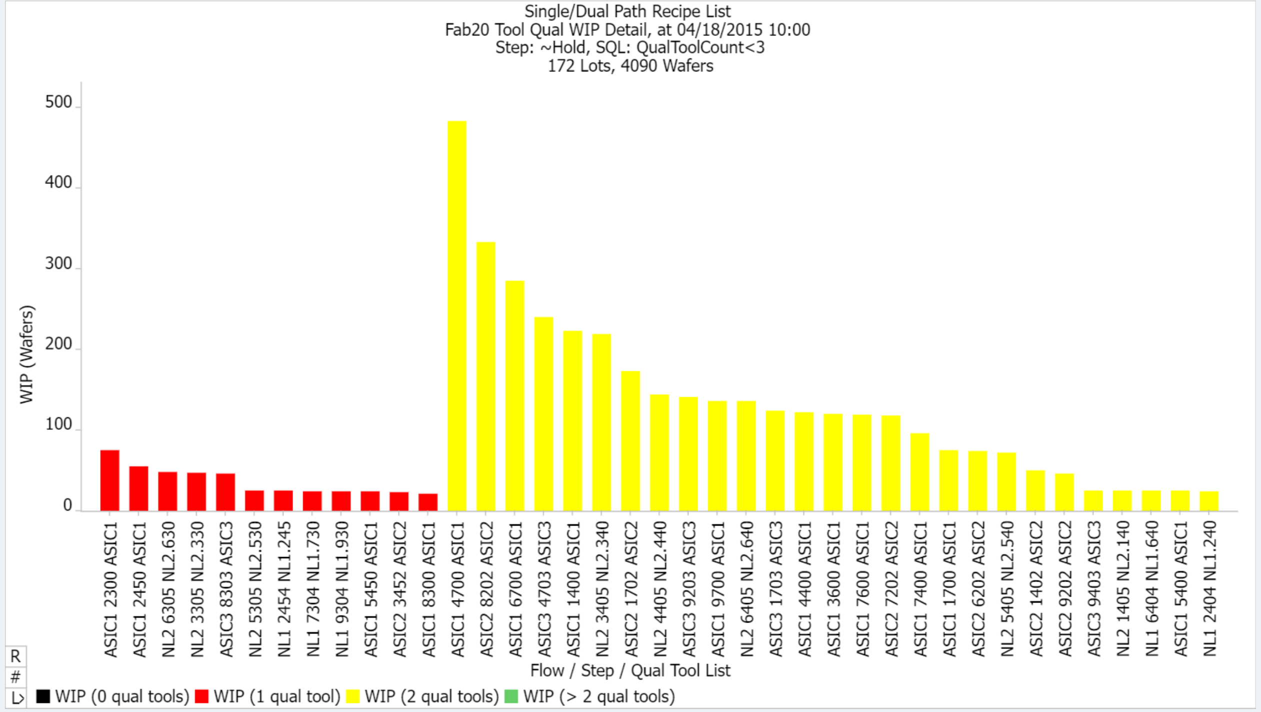
- Shared line vs. dedicated lines at stores or the airport. Shared line is much faster, on average.
- Single lane road vs. multi-lane road. We will end up behind the slow car(s) on the single lane road.

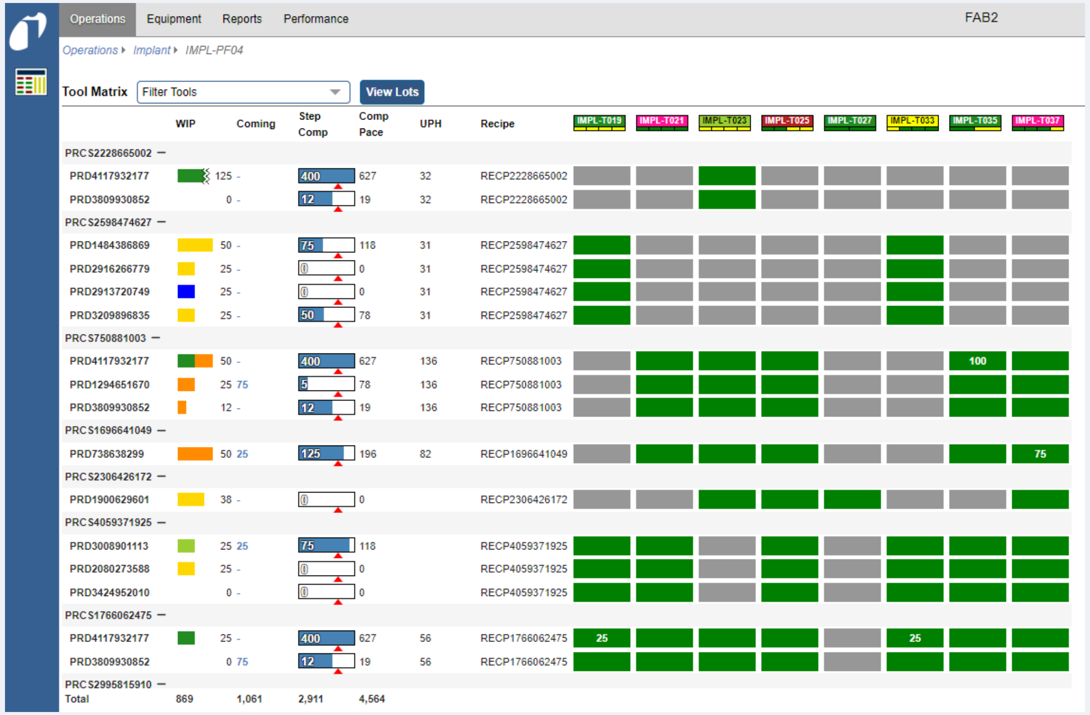


We highly recommend keeping single-path operations visible in fab reports

The FabTime chart on the left shows, for all route-step combinations that have WIP waiting, the number of tools qualified to run that step. Steps with more than two tools are not displayed.

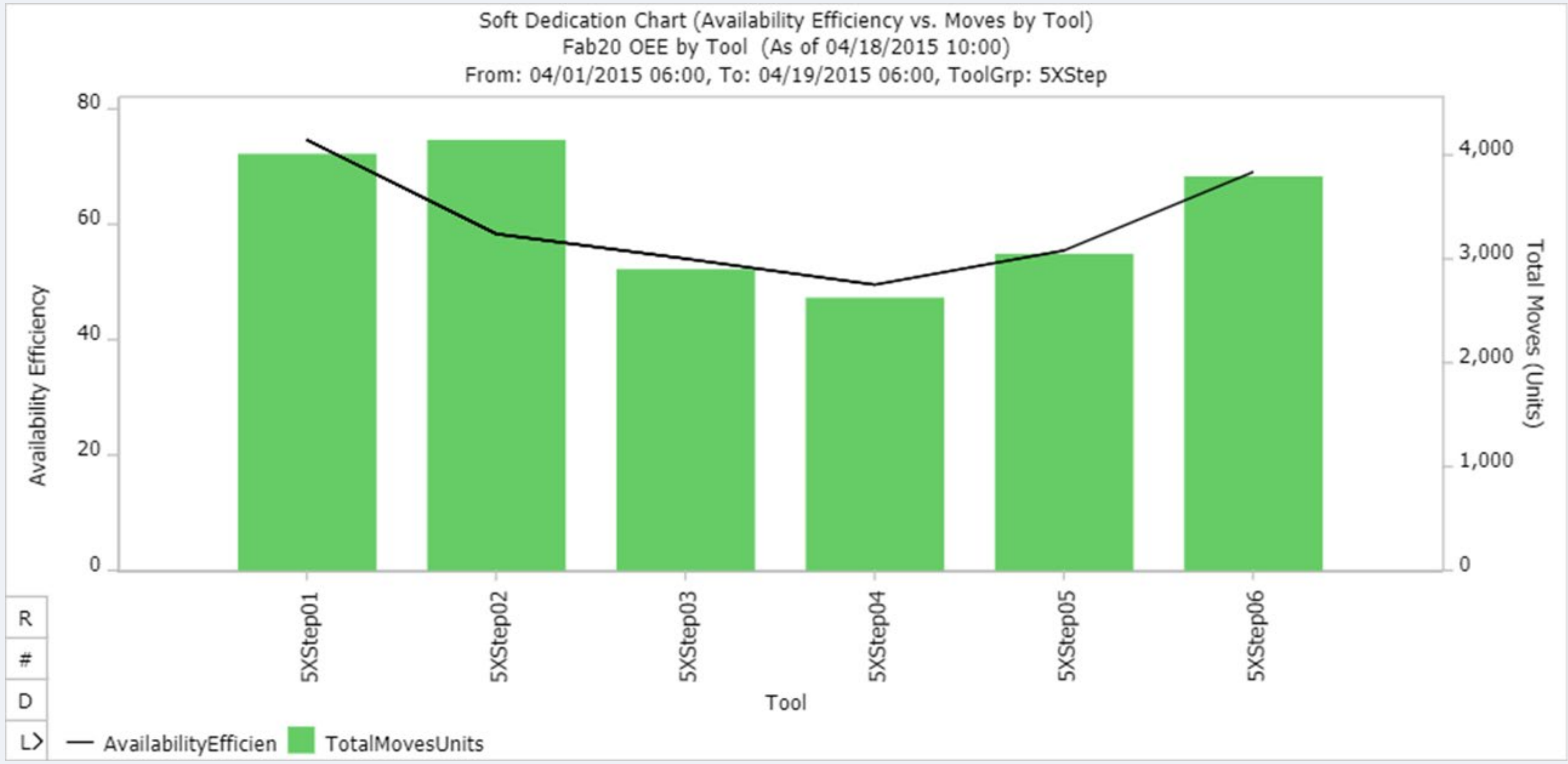
The FPS Dashboard chart on the right shows which implant tools are qualified for which processes.





It’s also useful to identify where “soft dedication” is occurring

- Soft dedication is when operators have preferences for certain tools (layout, speed, etc.)
- Graphing availability efficiency and moves by tool for a tool group can show where a tool has higher or lower moves than availability would predict.
  - 5xStep02 has extra moves in this example.



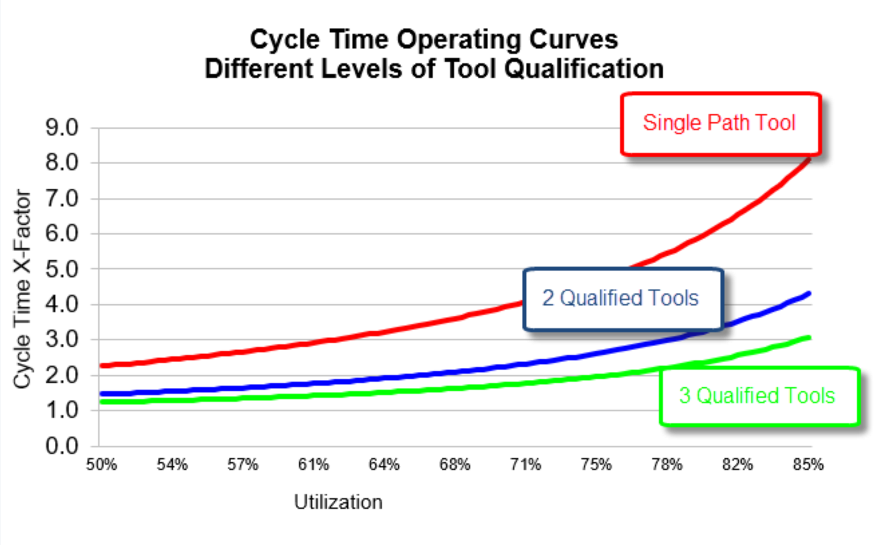
How should fabs manage tool qualification to improve performance?

Education:

Teach team members (especially process engineers) the impact of tool qualification on cycle time curve.

Systematically monitor and reduce:

- Active constraints (especially complex constraints!).
  - Do all constraints have an expiration date?
- Impaired recipes / disabled tool capabilities.
- Single-path operations.
- Soft-dedication due to preferences / inconvenient tool location.



Take home message: If you're going to do one thing to improve fab cycle time, qualify a second tool everywhere you can.

Wrapping Up

Utilization, Variability, and Tool Qualification issues all drive cycle time higher. Understanding the cycle time impact of these factors helps your organization identify and prioritize opportunities for cycle time reduction (= profitability improvement).

Recap: The 3 fundamental drivers of fab cycle time

Utilization = Productive / (Productive + Standby)

- For single tools, operating curve shaped like X-Factor = 1 / (1 – Utilization). When utilization approaches 100%, CT gets very high.
- **Converting unavailable time and forced idle time to true standby time improves CT.**

Variability changes the shape of the operating curve

- X-Factor ~= 1 + [Utilization/(1-Utilization)] * [Variability Factor]
- Reducing variability (arrival, process, downtime) reduces cycle time.
- **Opportunities to reduce fab variability abound, especially around tool downtime and PM scheduling.**

Number of qualified tools is the 3rd core driver of CT

- Increasing number of qualified tools and decreasing soft dedication can improve CT for new products.
- **Moving from one qualified tool to two can cut operation cycle time by 50%, with smaller increases as more tools are qualified.**

Which of these do you think would be most useful for you?

For more ideas: subscribe to the FabTime Cycle Time Newsletter

If the content in this webinar seems useful to you, consider subscribing to the FabTime Cycle Time Management Newsletter (now distributed by INFICON)

- Bi-monthly email publication, currently sent as PDF attachment, 2800+ subscribers, 180+ past issues
- Articles about improving fab productivity, with subscriber discussion, community and industry news, and cycle time tips

Recent Topics:

- Cycle Time and Holds
- Forward-Looking Cycle Time Metrics
- What Makes an Effective Daily Fab Status Meeting?
- Managing Operators during a Staffing Shortage

Next topic: Improving communication about fab equipment reliability

Email jennifer.robinson@inficon.com to subscribe or message me on LinkedIn: https://www.linkedin.com/in/jenniferrobinsoncycletime/

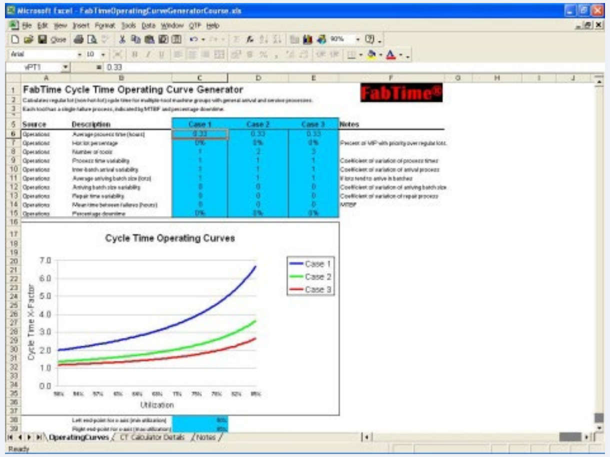
Focusing on the fundamental drivers of CT can help fabs improve profitability

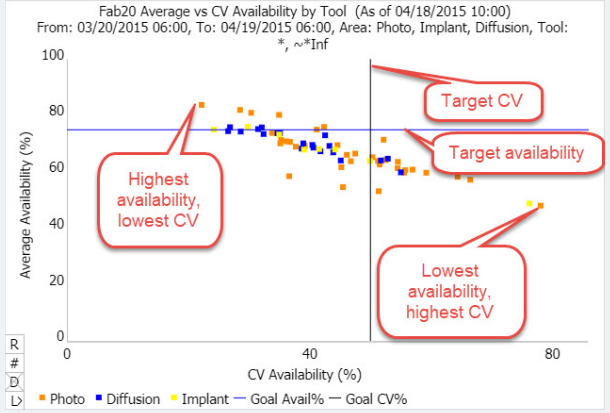
Cycle time can be reduced with $$$ (tools and staffing).

- This is often infeasible for various reasons.

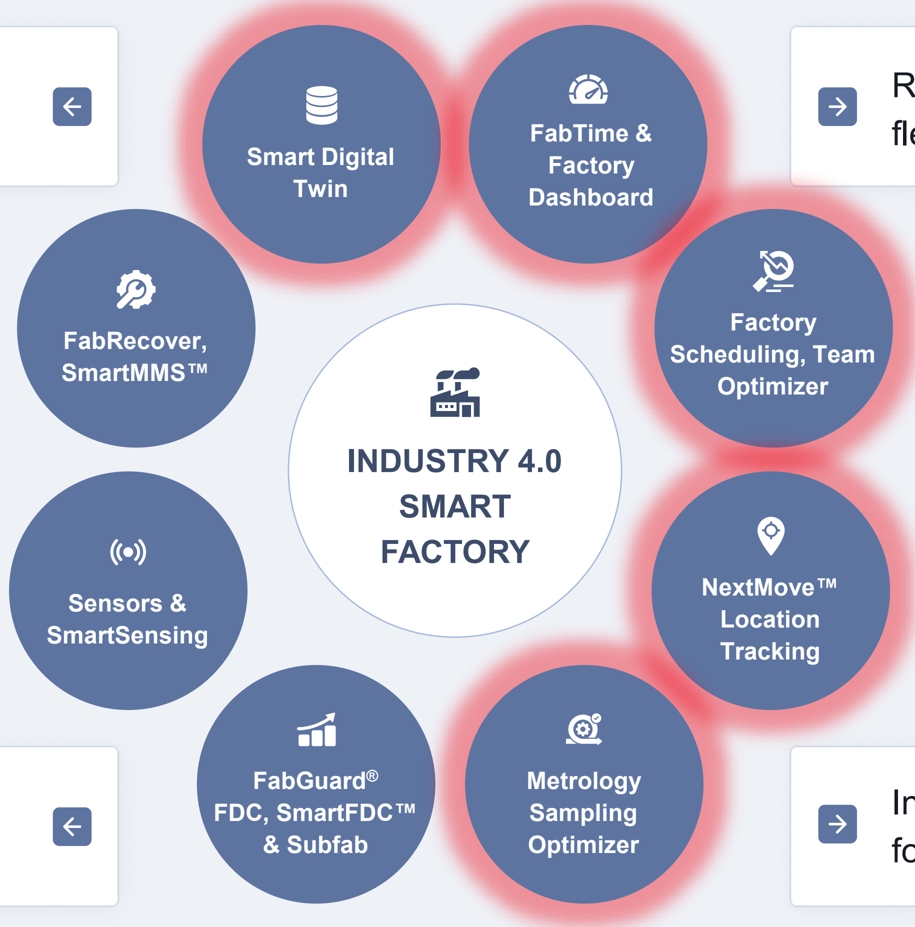
Cycle time can also be reduced with education and behavior changes.

- **Step 1:** Use operating curve concepts to understand the implication of operational decisions on cycle time (PM strategies, tool dedication policies, etc.)
- **Step 2:** Use actual data to pinpoint problem areas, especially where cycle time is worse than goal. Knowing where the problems are is the first step to improving them.
- **Step 3:** Take action in your fab. Make some changes and measure their impact. Use software and control tools like a factory scheduler to help.





INFICON can help via our course and complete portfolio of Smart Solutions



- Learning data warehouse and factory physics engine
- Optimized maintenance timing and labor
- Process aware sensing solutions
- Tool & process monitoring for reduced scrap
- Real-time factory priorities, flexible user-customized reporting
- Global optimization of Return on Assets
- Optimized Scheduler based WIP movement
- Intelligent integrated sampling for reduced risk at lower cost

Please reach out to jennifer.robinson@inficon.com for more information.

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