FabTime Cycle Time Management Newsletter

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Information

Mission: To discuss issues relating to proactive wafer fab cycle time management.

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Welcome

Welcome to Volume 3, Number 9 of the FabTime Cycle Time Management Newsletter. This month we have subscriber discussion on capacity planning using simulation, as well as using fab-level metrics for understanding variability. We also present the results from last month's survey question about the number of certifications per operator that people have in their factories. We would like to thank the people who took the time and made the effort to respond to this survey question. Their names are not being shared publicly, to protect their confidentiality.

Our main topic this month also concerns operators. We explore the impact of staffing levels on cycle time, and give examples from simulation models that show how operator delays can lead to forced idle time on tools, even at relatively low levels of operator loading. We cover this topic in more detail as part of FabTime's 2-day Cycle Time Management Course. We'll be giving a multi-company session of the course in the Bay Area next week (details below). There are still a couple of spots left available. If you are interested in attending the course, please let me know as soon as possible.

Thanks for reading! -- Jennifer

FabTime

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Community News/Announcements

FabTime Cycle Time Management Course

Earlier this week we gave a session of the 2-day FabTime Cycle Time Management Course at a company site on the East Coast. A multi-company session of the course will be held November 6-7 at NEC Electronics Inc. in Santa Clara, CA. There are still a couple of spots left in this session of the course (open to people from any company, for a fee). If you are interested in attending, send email to Jennifer.Robinson@FabTime.com as soon as possible.

FabTime welcomes the opportunity to publish community news and announcements. Simply send them to Jennifer.-Robinson@FabTime.com.

Subscriber Discussion Forum

An Approach to Capacity Planning Using Dynamic Simulation

Ramesh Rao of National Semiconductor in Arlington, Texas gave a presentation on using simulation for capacity planning at the recent Brooks Automation Symposium in Phoenix. The presentation was well-prepared and well-received. Ramesh asked us to publish a short summary of the publication, because he ends with several open questions, and he thought our newsletter community might have useful thoughts to contribute on this topic.

"A pure static model approach to capacity analysis for high volume wafer manufacturing fabs producing a wide mix of products on many different types of technologies has several limitations, especially when there are very stringent cycle-time requirements. Simulation analysis can overcome these limitations and provides endless possibilities for analyzing details. However, the biggest problem with simulation analysis for ramping is the turnaround time due to the large number of iterations required (especially when there are hidden bottlenecks that require multiple simulations to identify).

We have developed a process using a combination of static modeling and dynamic simulations. A simulation extension (called the Supervisor) has been developed to monitor and add or remove tools dynamically during simulations based on a predefined set of triggers. The key advantage to this approach is that a detailed dynamic simulation-based analysis for capacity planning can be completed within a small number of iterations (2-3).

The supervisor process wakes up at periodic user-defined intervals during the simulation and compares current performance of each tool to its triggers. Any tool that violates its triggers is flagged. If the tool was flagged in the previous pass as well, it is considered a candidate for cloning (adding capacity) in the current pass, or else its flag is reset. If more than one tool in a family is flagged the worst-case violator is selected and cloned. The flag on the cloned tool is reset.

The choice of triggers plays an important role in this approach. At National, we have used WIP and Current WIP Queue Time (at a given tool) as triggers. Thresholds on the triggers need groundwork to develop empirical calculations based on knowledge of organization goals and fab performance. The solutions were validated against previous analysis. The WIP Trigger approach has been used in real-life capacity planning exercises. After initial tuning of the triggers we used 3-4 iterations on average (~2.5 days for analysis).

Future Directions / Topics to Ponder

We are working on a similar process to turn off tools during a ramp down (for cost savings). We are investigating other triggers and combinations thereof. Currently the thresholds for the triggers are determined in an empirical way (some understanding of past tool performance, some guess work, and a good bit of trial and error). We would like to establish more formal methods to determine thresholds for the triggers and would like to limit the process to two iterations per analysis. We consider this to be a work in progress and would appreciate any feedback, inputs, suggestions, and recommendations, especially in the triggers department. For example:

- Are there any mathematical relationships and/or calculations that could be used to determine the thresholds for the triggers so that the process can be automated for any model?

- What is a good set or combination of triggers to be used? The ideal case would be to set the overall cycle-time requirements and develop a relationship between overall cycle-time and the different metrics of individual tools to identify the tools that are key to meeting the cycle-time requirements for a given mix.

Is anyone aware of related or similar work in the literature?"

FabTime Response: We hope that some of our other subscribers will have thoughts to share with Ramesh on this topic.

Fab-Level Metric for Variation

Sara Anderson of Seagate Technology wrote this month and asked: "In one of your first issues there was discussion around the question "what do you think is the biggest source of variability in a wafer fab?" There were several responses and opinions as to what these sources are. Knowing what the sources are is extremely valuable. However, once the sources of variability are known, what is the best way to quantify the overall fab variability? Is there one metric, or a small set of metrics, that give an overall output of how well the factory is doing in regards to variation?"

FabTime Response:

I don't know of a single metric that measures overall fab variability. However, what I would recommend is measuring the coefficient of variation of the time between arrivals to critical operations and/or tool groups in your fab. Coefficient of variation is a statistical measure equal to (Standard deviation) / (Average). It's a normalized measure of how widely the individual values are dispersed. Typical academic studies assume that the coefficient of variation of interarrival times in a fab is 1 (matching an exponential distribution, which is moderately variable). Our experience has been that in fact, fabs are so highly variable that coefficients of variation for interarrival times can be much higher than 1 (in simulation models I have seen this as high as 4 for individual operations). This is because of batch lot releases into the fab and batch processing, among other sources of variability such as equipment downtimes.

We cover this quite a bit in our cycle time management course. We also have charts in our FabTime software that display coefficient of variation of interarrival times as both a trend and as a pareto (by tool, operation, etc). You should be able to get this type of information out of your MES as some kind of custom report/query, though it will probably not be in your standard reports.

Operator Certification/Cross Training

Last month we asked a survey question concerning the number of different operator certifications per operator that was typical at different fabs. Specifically, we asked people to tell us three things:

1. At what level do you measure certifications (recipe, tool type, or module/area)?

2. In terms of the above, about how many certifications do you have, on average, per operator?

3. Approximately how many operators do you have (total, across all shifts)? This is so that we can see if the answers vary for larger vs. smaller fabs.

We received data back from 16 facilities, mostly wafer fabs, but also a few probe, PCB, and silicon wafer manufacturing sites. The majority of these facilities (12) measure number of certifications by tool-type, along with two facilities that measure by individual tool, one by operation area, and one by recipe. The average number of certifications per operator across these 16 facilities was 6.31, ranging from 2.2 up to 18. There were an average of 560 operators at each facility, ranging from 100 to 1500.

There does appear to be some variation between larger and smaller fabs. The average number of certifications per operator across all facilities with 400 or fewer operators (10 sites) was 7.58. The average across all facilities with more than 400 operators (6 sites) was 4.2. Note, however, that individual responses varied considerably, and that the facilities with 400 or fewer operators included a small R&D fab and the one fab in the study that measured certifications by recipe (the two fabs with the highest number of certifications per operator). More detailed results, including the individual values for the 16 facilities, will be shared with the people who submitted data. We would also like to thank those who took the time and trouble to share data - their names not being shared publicly, to protect their confidentiality.

Would people like to see other informal survey questions like this? Send us your feedback and suggestions. Thanks!

The Impact of Staffing on Cycle Time

Introduction

Estimating the impact of staffing on cycle time is a non-trivial task. It is impossible to accurately model all the tasks and activities of a human operator, so we won't even start down that path. What we have done is created a section in our cycle time management class where we focus specifically on the issue of forced tool idle time due to operator delays. We started with this basic thought-process:

1) Cycle time is driven most heavily by utilization.

2) Given factory E10 data (tool state data), we estimate utilization as (Productive Time) / (Productive Time + Standby Time).

3) Whenever a single operator is responsible for multiple tools, there is the possibility of forced tool idle time at these points (and possibly others):

> 3a) A tool is idle when there is WIP waiting to be loaded, but the operator is busy elsewhere.
>
> 3b) A tool is idle waiting to be unloaded, but the operator is busy elsewhere.

4) Forced idle time should not be counted as part of Standby Time.

5) Forced idle time drives up utilization, and thus likely increases cycle time.

6) The actual delay incurred waiting for the operator will also increase cycle time.

In Search of Intuition

We first went looking for a basic model that would supply us with intuition. Nothing too fancy -- just something that we could use to compare scenarios, with inputs such as:

- Number of tools.
- Load / process / unload times and distributions.
- Arrival rate and distribution of incoming lots.

And outputs such as:

- Estimated cycle time.
- Estimated (true) standby time on the tools, not counting forced idle time.
- Estimated standby time for the operator.

We have a nice analytical approximation from Hermann Gold for the operator/tool interference problem (see reference below), but we wanted a visual example we could use for teaching. Therefore, we put together a small simulation model. This took about an hour, and after some experimentation and comparison with analytic models for reduced cases, we were reasonably confident in our simulation results.

Sample Results

We suspected that the impact of forced idle time would be large, but we didn't have a feel for how large. Our sample results indicate that the effect is dramatic, especially in the presence of process time variability.

For example, consider the following scenario:

- One operator, 3 tools
- 20 minute process time per lot (including 2 minute load, 2 minute unload)
- 8 minute average time between lot arrivals.

Here are the relevant arrival rates, capacity, and basic utilization numbers:

Tools:

- Theoretical cycle time = 20 minutes
- Capacity = 3 tools * 3 lots per hour = 9 lots per hour
- Arrival rate = 7.5 lots per hour
- Loading = 7.5 / 9 = 83%

Operator:

- Capacity = 15 lots per hour (4 minutes required for each lot).
- Arrival rate = 7.5 lots per hour
- Loading = 7.5 / 15 = 50%

If we remove the operator constraint and use exponential inter-arrival times and process times, this is an M/M/3 queue, and analytic models predict:

- Avg Cycle Time ~ 46 minutes
- Cycle Time X-Factor = Avg Cycle Time / Theoretical = 2.3X
- Tool idle time ~ 17%

(And in fact, we checked our simulation model by removing the operator and it gives the same approximate cycle time).

When we added the operator constraint, we received (10 x 5,000 hour simulations):

- Avg Cycle Time ~ 75 minutes (Standard Deviation across replications = 3.7 minutes)
- Cycle Time X-Factor = Avg Cycle Time / Theoretical Cycle Time = 3.75X
- Tool idle time ~ 7%

We found that operator delays had caused the standby time on the tools in the simulation to fall from a predicted value of 17% to about 7%. So the tools were effectively running at 93% utilization instead of 83%. It is interesting to note that the analytic cycle time X-Factor approximation for an M/M/3 queue running at 93% utilization is 4.8X -- well above our simulated result of 3.75X.

We also experimented by taking all variability out of the load, process, and unload times (we told the simulation model that these times were always constant values). We received these results:

Without operator constraint:

- Avg Cycle Time ~ 36 minutes (StdDev across replications = 0.8 minutes)
- Cycle Time X-Factor = Avg Cycle Time / Theoretical = 1.8X
- Tool idle time ~ 17% [As we expect].

With operator constraint:

- Avg Cycle Time ~ 48 minutes (StdDev across replications = 2.6 minutes)
- Cycle Time X-Factor = Avg Cycle Time / Theoretical = 2.4X
- Tool idle time ~ 12%

So once again, we see forced idle time on the tools, and increased cycle time (from 1.8X to 2.4X). The effect is not as large, but it is still present.

To summarize:

Model	CT XFactor	Tool Idle%	Notes
(a)	2.3 X	17%	Baseline with no operator constraint
(b)	3.75 X	7%	Baseline + operator constraint
(c)	1.8 X	17%	Baseline (constant process), no operator
(d)	2.4 X	12%	Baseline (constant process) + operator constraint

Summary

We are interested in estimating the impact of staffing on cycle time. Rather than tackle this issue in detail, we focused on one particular aspect - forced idle time on tools due to operator delays. To look at this visually, we built a very simple simulation model to study the issue.

We found that even in models with only 3 tools, and light operator loading (50% busy), operator delays may increase cycle time significantly. Our example gave these cycle time results:

1) Variability in both arrivals and process time:

- 2.3 X theoretical (no operator constraint) --> 3.75 X theoretical (with operator constraint).

2) Variability in arrivals, constant process times:

- 1.8 X theoretical (no operator constraint) --> 2.4 X theoretical (with operator constraint).

We believe these increases in cycle time are due to a combination of factors:

- Forced idle time reduces the capacity of the tools and moves them onto the steeper part of the cycle time vs. utilization curve.

- Some lots incur additional cycle time waiting for the operator to load/unload.

We have not done the analysis necessary to know which of these factors is primarily responsible for the increase in cycle time (perhaps this is a good MS student project if it has not already been done!)

And finally, please be warned -- we only simulated a few cases, you should not extrapolate these results to all situations! But we will point out that the results will likely be even more dramatic when operators are more highly loaded, or when they are shared across more tools than three. Whenever the forced idle time from operator delays forces your tools into a region of higher effective utilization, you might see much higher cycle times than you expect.

Recommendations

Operator delays may be subtle, and can occur even at low operator utilization values. If possible, use real data from the fab to monitor these delays and estimate their impact, especially for your bottleneck tools. You can use simple simulation models to gain insight into particular situations.

Closing Questions for FabTime Subscribers

- Do you measure the percentage of time that your tools spend waiting for operators?

- Do you include operators in your capacity and simulation models?

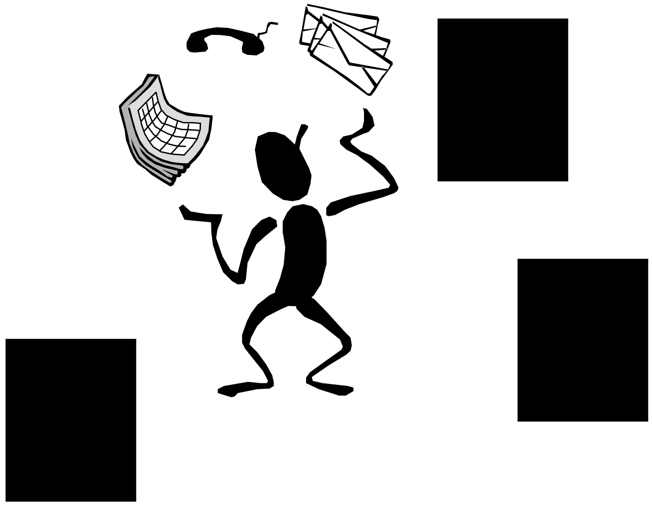
- Do you think that operator loading levels are contributing to cycle time in your fab?

Further Reading

- H-N Chen and R. Dabbas, "Modeling Staffing Requirements within a Semiconductor Manufacturing Environment," *Proceedings of the 2002 Advanced Semiconductor Manufacturing Conference*, Boston, MA, 234-239, 2002. This paper describes a Motorola in-house project to build a staffing model with static capacity, queueing, and simulation. A PDF of the presentation from this paper can be requested from Jennifer.Robinson@FabTime.com.

- H. Gold, "A Simple Queueing Model for the Estimation of Man Machine Interference in Semiconductor Wafer Fabrication," *Operations Research Proceedings 2001 (OR 2001)*, Duisburg, Germany, September 2001. In this paper a simple queueing model to deal with the man machine interference problem in semiconductor manufacturing is developed. The aim is to estimate the cycle time increase at a work center due to the fact that each lot entering a work center brings in not only work for the machines but also for the operators. A PDF of this paper can be requested from Jennifer.Robinson@FabTime.com.

- R. C. Kotcher, "How "Overstaffing" at Bottleneck Machines Can Unleash Extra Capacity," *Proceedings of the 2001 Winter Simulation Conference*, Washington, D.C., 1163-1169, 2001. Using simulation, Headway Technologies predicted that increasing staffing among a group of already lightly loaded machine operators (overstaffing) would significantly improve throughput of its factory. This was counterintuitive since the operators already had significant idle time. Yet time studies confirmed that bottleneck equipment for which these operators were responsible was spending over 22% of its uptime idle solely due to lack of an operator. Analysis showed how this could be so: production equipment has a frequent and unpredictable need for operators, yet the operators must spend time away from the equipment tending to other demands of their jobs. A method of estimating the cost of this operator-induced throughput loss is described. This paper can be downloaded from www.informs-cs.org/wscpapers.html.



FabTime Recommendations

Queueing ToolPak

The Queueing ToolPak is an Excel add-in that provides spreadsheet functions to calculate performance measures for M/M/s queueing systems, including systems with a capacity limit and systems with a targeted level of service. Once you install it, the ToolPak functions appear as a category within Excel's standard function wizard. There are functions for average server utilization; average number of customers in queue and in system; average time in queue and in system; probability that system is empty; probability that a customer will have to wait; probability that a potential customer will balk (due to the queue being full); probability of observing the system in a particular state; probability that a customer will wait less than some threshold time; minimum number of servers needed to achieve a specified service level, assuming that system capacity is fixed; and minimum number of servers needed to achieve a specified service level, assuming that queue capacity is fixed. We found the Queueing ToolPak easy to use, and a nice convenience to save having to code these formulas into spreadsheets ourselves. The Queueing ToolPak is available free from http://www.bus.ualberta.ca/aingolfsson/qtp/, and is maintained by Professor Armann Ingolfsson at the University of Alberta.

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