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 Issue #8 of the FabTime Cycle Time Management Newsletter. In this issue, we have a response to last month's newsletter topic from Tim Stanley. Tim suggests that an additional method of cycle time improvement lies in integrating single-wafer tools, to avoid forming transfer lots. We also have a response from V.A. Ames to our earlier discussion of performance measures, in which V.A. points out an important omission in our characterization of OEE. Finally, we have a book recommendation from Arnie Stein. We appreciate Tim, V.A., and Arnie all taking the time to write, and encourage others to write to us, too. We'll only include your comments in future issues with your permission.

The topic for this issue is Understanding the Impact of Single-Path Tools, by Frank Chance. It is well-known among production personnel that the presence of single-path tools increases cycle times. However, we thought there would be benefit in providing a concrete example that illustrates why this is true and how queueing models can be used to quantify the effect.

This will be the last newsletter issue of 2000. Thanks for reading, and for sharing this newsletter with your colleagues. You've helped us to grow the newsletter from the glimmer of an idea to a regular publication. Frank and I would like to wish you all a safe and happy holiday season, and a prosperous 2001. We look forward to talking with you again in the New Year -- Jennifer

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Responses To Prior Newsletter Topics

Issue #7 (Cycle Time Reduction at Non-Bottleneck Tools)

From Tim Stanley (SEMATECH) - "An additional suggestion for cycle time improvement is to integrate single wafer tools, so that transfer lots do not need to be formed. For example, integrating metrology in CMP and Litho tools.

What would be ideal would be to have a fab built using all single wafer tools, with each wafer passed on as soon as each process was completed. (Transfer lot size equal to one). Unfortunately this approach is not possible for reliability, flexibility, and tool availability considerations. But integrating metrology should be possible.

Another approach is to remove non value added steps, like transport into and out of stockers. Stockers hide the WIP so that the operator needs to go and find it.

A standard feature of 300mm equipment is to include a local buffer or multiple load ports on each tool, which should help cycle time as well as bottleneck utilization since the operator does not need to take action the instant a lot finishes to prevent loss of time and capacity in starting the next lot."

Issue #6 (Performance Measurement in Wafer Fabs)

V.A. Ames (Applied Materials) wrote to take exception to our suggestion that OEE is not a useful metric for non-bottleneck tools. We had made the initial statement because, in it's standard form, OEE penalizes tools for idle time, even when that idle time is due to low equipment loading. V.A. pointed out that, while he agreed with this general logic, "we added a calculation called Production OEE in SEMI E79 that measures OEE while there is product in the area, making it compatible with the bottleneck tool." So, we thank V.A. for pointing out our omission, and only add that we think that for non-bottlenecks you should use this "production OEE" metric, rather than the standard OEE calculation.

Understanding the Impact of Single-Path Tools

Background

Single-path tools are a common feature in wafer fabs. They occur whenever a single tool is the only piece of equipment qualified to process a particular operation. During fab startup, the majority of equipment will be single-path (since only one tool of each type has been purchased). As fab volume grows, and duplicate tools are brought on-line, the number of single-path tools is usually reduced. At this point, however, there is often a choice in how the duplicate tools are configured -- cross-qualified in some fashion, or dedicated to individual operations. In the following discussion we will examine the impact of this decision on the number of single-path tools, and ultimately on cycle time. For example, suppose we have this very simple process flow:

Start
Operation 100 - ToolType A (Layer 1)
Operation 200 - ToolType A (Layer 2)
Operation 300 - ToolType A (Layer 3)
Operation 400 - ToolType B (Layer 4)
Ship

Note that for illustration purposes, we have omitted the intervening operations between each operation listed above. In a real fab there could be dozens and dozens of steps between layers. Suppose our tool capacities are:

ToolType A - 70 wafers per hour
ToolType B - 100 wafers per hour

If we start 20 wafers per hour, we'll need the following tool capacities:

ToolType A - 20 wafers per hour * 3 visits per wafer = 60 wafers per hour
ToolType B - 20 wafers per hour * 1 visit per wafer = 20 wafers per hour

At this start volume, we can get by with a single ToolType A tool (let's call it A#1), and a single ToolType B tool (B#1). So we have:

Start (20 wafers per hour)
Operation 100 - A#1
Operation 200 - A#1
Operation 300 - A#1
Operation 400 - B#1
Ship

In this case A#1 is a single-path tool (it has three single-path operations), and B#1 is also a single-path tool (it has only one single-path operation). As volume grows, however, we will add more ToolType A tools.

For example, if our starts triple to 60 wafers per hour, we'll need the following tool capacities:

ToolType A - 60 wafers per hour * 3 visits per wafer = 180 wafers per hour
ToolType B - 60 wafers per hour * 1 visit per wafer = 60 wafers per hour

At this increased start volume, we will need two additional ToolType A tools (A#2 and A#3), but our single B#1 tool will continue to suffice. If we cross-qualify the additional tools to run all operations, we will have this configuration:

Cross-Qualified Configuration

Start (60 wafers per hour)
Operation 100 - A#1, A#2, or A#3
Operation 200 - A#1, A#2, or A#3
Operation 300 - A#1, A#2, or A#3
Operation 400 - B#1
Ship

Thus, as volume increases, and we purchase duplicate tools, if these new tools are cross-qualified, the number of single-path tools will decrease.

Suppose, however, that it is expensive or time-consuming to cross-qualify ToolType A tools. In that case, we may wish to dedicate operations to particular tools, and choose this configuration:

Dedicated-Tool Configuration

Start (60 wafers per hour)
Operation 100 - A#1
Operation 200 - A#2
Operation 300 - A#3
Operation 400 - B#1
Ship

Note that this configuration is equivalent to the previous one in a capacity sense (the utilization of equipment will be the same in each configuration). But the configurations do not have equivalent cycle times! Even though we have more equipment, the number of single-path tools has increased from 2 to 4.

Cycle Time Comparison

To compare the two configurations, we'll need more process information. Let's use the following:

1) 20-wafer lots
2) ToolType A - 17 minutes to process a lot of 20 wafers
3) ToolType B - 12 minutes to process a

lot of 20 wafers

We'll perform a comparison based on queueing theory. For the cross-qualified configuration, we'll use the M/D/s approximation, and for the dedicated-tool configuration, we'll use the M/D/1 approximation. The use of these formulas involves some further technical assumptions (independence of arrivals, etc) that we'll blissfully ignore.

For our purposes, we'll simply note that these formulas assume that the times between lot arrivals are highly variable (the M stands for Markovian), and that process times are constant (the D stands for Deterministic). That is, we assume that a lot always takes exactly 17 minutes to process on ToolType A, and exactly 12 minutes to process on ToolType B, but the times between lot arrivals to ToolType A and ToolType B vary. The third value in each approximation name stands for the number of machines, where *s* is shorthand for multiple machines (three machines in this example). Using queueing theory, we get the following predicted average cycle times:

"the dedicated-tool configuration results in an average cycle time that is nearly twice as long"

Cross-Qualified Configuration

- Operation 100 - Queue Time = 13.8 minutes, Process Time = 17 minutes, Cycle Time = 30.8 minutes.
- Operation 200 - Queue Time = 13.8 minutes, Process Time = 17 minutes, Cycle Time = 30.8 minutes.
- Operation 300 - Queue Time = 13.8 minutes, Process Time = 17 minutes, Cycle Time = 30.8 minutes.
- Operation 400 - Queue Time = 9 minutes, Process Time = 12 minutes, Cycle Time = 21 minutes.
- Total Queue Time = 50.4 minutes.
- Total Process Time = 63 minutes.
- Total Cycle Time = 113.4 minutes.
- Total Cycle Time over Total Process Time = 1.8X.

Dedicated-Tool Configuration

- Operation 100 - Queue Time = 48 minutes, Process Time = 17 minutes, Cycle Time = 65 minutes.
- Operation 200 - Queue Time = 48 minutes, Process Time = 17 minutes, Cycle Time = 65 minutes.
- Operation 300 - Queue Time = 48 minutes, Process Time = 17 minutes, Cycle Time = 65 minutes.
- Operation 400 - Queue Time = 9 minutes, Process Time = 12 minutes, Cycle Time = 21 minutes.
- Total Queue Time = 153 minutes.
- Total Process Time = 63 minutes.
- Total Cycle Time = 216 minutes.
- Total Cycle Time over Total Process Time = 3.4X (!!!).

Single-Sentence Summary

Based on our first-pass queueing analysis, the dedicated-tool configuration results in an average cycle time that is nearly twice as long as the cross-qualified configuration.

Further Explanation

For those not convinced by our queueing analysis, some further explanation is due as to why dedicated-tool configurations result in longer average cycle times. Suppose you have a tool that is busy 50% of the time. With highly random arrivals, any arriving lot has a 50% chance of arriving and finding the tool busy. Now suppose that you have two tools, each busy 50% of the time. It will often be the case that both tools will be busy at the same time (if there is a lot of WIP waiting in queue, then both tools will be busy). However, it is not always the case that both tools will be busy at the same time, thus, there is a higher

likelihood that a lot will arrive and find at least one free tool in the cross-qualified configuration. This is one advantage of cross-qualification -- more frequent immediate access to an idle tool.
For a second advantage, think about where we see cross-qualification in real-life. For example, most airline check-in counters have multiple (cross-qualified) representatives, and a single waiting line, even though customers might have a variety of service requests (operations) -- checking in bags, changing seats, etc. There may be a separate, dedicated server for first-class customers (hot lots).

At the airport, you can see that a major advantage of cross-qualification is protection from (painfully) long service times. If there are 5 representatives, it's not so bad that the person in front of you gets into an argument with the agent over the amount of luggage they can check -- you'll probably end up being served by a different agent. You'll notice that our wafer fab example doesn't even take this advantage into account - we've assumed that process times are constant. If you relax this assumption and allow variable process times, the advantage of cross-qualification grows even larger.

Side-Note about Simulation

Note that if you simulate the exact configurations listed above, you will find that the dedicated-tool configuration does not match the queueing results above. That's because the constant process times squelch the arrival variability for operations 200, 300, and 400. Thus there is effectively no queueing at all for these operations, and the dedicated-tool configuration looks much better by comparison. However, remember our very first simplifying assumption - we have removed all of the operations that would normally lie between layers... if you include those operations, and you include multiple routes sharing the same equipment (a common feature in fabs), the variability in arrival times will reappear, making the queueing approximation more realistic than the simulation results.

Side Note About Equipment Downtime

This discussion has not explicitly included downtime (though equipment failures are a major contributor to variability in lot arrival times in a wafer fab). Obviously, if you have a single-path tool, and that tool goes down for a major failure, all lots that depend on the single-path tool will be delayed. This can lead to significant queueing delays, and can also cause WIP bubbles when the tool goes back up. The example above shows that even without such downtimes, single-path tools still have significantly longer waiting time, on average.

Discussion

These results suggest that single-path tools can have a very negative impact on cycle times. Please note, however, that this impact has been demonstrated with a choice between a 100% cross-qualified configuration, and a 100% dedicated-tool configuration. In reality, confounding factors will likely arise:

- 100% cross-qualification won't be feasible due to contamination issues.
- 100% cross-qualification won't be feasible due to secondary-equipment constraints (availability of masks, specialized tooling, etc).
- Even if tools can be cross-qualified, there may be non-trivial setups to consider.
- Tool-dedication may be desirable because it makes the process easier to operate, and it reduces processing errors.

If you do have a legitimate choice between cross-qualification and tool-dedication, however, these results suggest that you should consider the cycle time benefits of cross-qualification when making your decision.

Additional References

For a discussion of tool-dedication and cross-qualification of steppers in an Infineon wafer fab, see the article by J. W. Fowler, S. Brown, H. Gold, and A. Schoemig, "Measurable Improvements in Cycle-Time-Constrained Capacity," Proceedings of the 6th ISSM Conference, October 6-8, 1997, San Francisco, A21-A24. You can request a PDF copy of the full paper from our website.

Other articles that discuss tool-dedication vs. cross-qualification in wafer fabs include:

- M. Mittler, "Two-Moment Analysis Of Alternative Tool Models With Random Breakdowns," *Proceedings of the 1996 IEEE Conference on Emerging Technologies and Factory Automation*, Kauai, HI, 546-552, 1996.

- P. K. Johri, "Overlapping Machine Groups in Semiconductor Wafer Fabrication," *European Journal of Operational Research*, Vol. 74, 509-518, 1994.

- R. C. Leachman and T. F. Carmon, "On Capacity Modeling for Production Planning with Alternative Machine Types," *IIE Transactions*, Vol. 24, No. 4, 62-72, 1992.

- D. Rohan, "Resource Sharing in Capacity Analysis," *Proceedings of the 1992 IEEE/SEMI Advanced Manufacturing Conference*, 39-42, 1992.

Of these four articles, only Manfred Mittler's paper tackles cycle time issues -- the other three are primarily concerned with capacity planning in the presence of overlapping equipment groups.

Community News / Announcements

Winter Simulation Conference

While this is very short notice, we'd like to point out that the Winter Simulation Conference starts on Sunday, December 10th, in Orlando, Florida. The final program, with abstracts, is available at http://www.wintersim.org/program.htm. Tom Jefferson asked us to especially point out the semiconductor manufacturing track, which has some great papers. Hope to see some of you there!

Address Change

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Of course you can still call Frank and Jennifer directly at 602-284-4726 (Frank) or 650-233-9193 (Jennifer).

FabTime welcomes the opportunity to publish announcements for individuals or companies. Simply send them to Jennifer.Robinson@FabTime.com.

FabTime Recommendations

■ FabTime's book recommendation of the month for December is "Root Cause Analysis", by Robert Latino and Kenneth Latino. Arnie Stein (Hyundai Semiconductor America) recommended this book to us, calling it "a very detailed, well edited, book that does a good job in really teaching RCA in a practical manner. Great potential for any industry." Both FabTime and Arnie caution that the book is somewhat expensive, and contains a bit of a sales pitch for the authors' products and services. However, it has some useful suggestions to offer, and we recommend it if you want to learn more about root cause analysis. You can find FabTime's more detailed review at www.fabtime.com/rootcause.htm.

■ SEMATECH Industry Economic Model. SEMATECH is undertaking an ambitious effort to model the dynamics of the chipmaking business, its equipment and materials supply chain. Jennifer attended a workshop in November in which the project's results to date were presented. While not directly relevant to individual lot cycle times (our focus), the workshop offered a fascinating peek at the larger trends in fab construction and technology. You can find more information about the project at www.sematech.org/public/resources/econmodl/index.htm.

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