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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Editor: Jennifer Robinson

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Welcome

Welcome to Volume 2, Number 10 of the FabTime Cycle Time Management Newsletter. This month we have a record-setting number of contributors. Several of the questions that we asked last month struck chords with people, and in this issue we have some great discussion on lot size for 300mm fabs, productivity reports, cost of cycle time (and how it relates to OEE), factory size, modeling operator impact, modeling cycle time during a ramp, and several other topics. My thanks to everyone who took the time to write. You are all helping to make this newsletter population into a real community of people interested in cycle time management.

Our new article this month is a continuation of last month's discussion on including cycle time in the capacity process. Last month we talked about how people do this implicitly, though the use of capacity loading factors. This month, we will talk about a more explicit method of including cycle time in the capacity planning process, through the use of simulation models. This article is based on a project that we did for Seagate Technology several years ago. Navi Grewal, one of the original authors, collaborated with us on this new article.

On behalf of FabTime, I wish you all a peaceful holiday season, and a Happy New Year. The FabTime Cycle Time Management Newsletter will be back in January.

Thanks for reading! -- Jennifer

FabTime

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Community News/Announcements

Job Change Announcement

Bob Kotcher is now Industrial Engineer at Maxtor's disk-manufacturing facility (formerly MMC Technology) in San Jose, California. He can be reached at (408) 570-3241 or BobKotcher@MMCTechnology.com.

FabTime to Collaborate with Lehigh on Cycle Time Management Research

Menlo Park, CA. November 13, 2001 - FabTime Inc. today announced that it would be collaborating with Dr. Theodore Ralphs of Lehigh University to advance cycle time management software tools. Specifically, FabTime will be supporting Dr. Ralphs in his research on decomposition-based algorithms for large-scale optimization problems.

FabTime specializes in cycle time management software for semiconductor wafer fabrication facilities (wafer fabs). The software pulls data from the fab's manufacturing execution system, analyzes it to look for cycle time cause-and-effect relationships, and presents the results in real-time to fab managers and supervisors.

"We would like to include a new generation of algorithms that perform more in-depth analyses, and alert fab management of potential cycle time problems that are building within the fab," said Dr. Frank Chance, president of FabTime. "To implement these algorithms we need to solve a variant of the generalized assignment problem. And we need to solve this problem quickly. That is where the work of Dr. Ralphs becomes important to us."

"Based on my preliminary technical discussions with FabTime," said Dr. Ralphs, "I believe that we may be able to exploit hidden structure within the problem to significantly cut solution run-times. Working with FabTime will help me to gain access to realistic problem data, and to get my results tested in a commercial environment."

About Lehigh University

Professor Ralphs is an assistant professor in the department of Industrial and Systems Engineering at Lehigh University. Since its inception in 1926, the ISE Department has focused on the analysis and design of manufacturing systems and processes, and on the efficient planning, control, and operation of production functions. The department's website is located at www.lehigh.edu/~inime/dept.htm.

Job Openings?

Due to the current industry downturn, we at FabTime know of a number of qualified people who are seeking positions. If your company is hiring, we can put you in touch with individuals seeking both manufacturing and industrial engineering positions. Just email newsletter@FabTime.com. We would also be happy to publish any notices of job openings in our newsletter. We hope that over the next few months, conditions will improve, and many more openings will be available.

Xilinx Projects Cycle Time Reduction from 300mm Production

On November 26th, Xilinx (San Jose, CA) announced that it had received its first good 300mm wafers from UMC's Fab 12A foundry, using the foundry's 0.15um logic technology. The full Xilinx press release is available at http://www.xilinx.com/prs_rls/01119umc.htm. An EBN article describing this accomplishment quoted Sandeep Vij, vice president of worldwide marketing at Xilinx on the anticipated cycle time impact of 300mm production.

"Fab 12A is a "lights-out" fab, meaning it's almost entirely automated, according to Vij. Fast robots move wafer boats from station to station, compressing cycle time by as much as one-third, to about two months or less, he said. As a result, Xilinx believes it will be able to respond more quickly to customer demand and better manage inventory." The full EBN article is available at www.ebnonline.com/story/OEG20011126S0046. The article also quotes Vij on projecting greater than 50% cost reductions due to 300mm production. Daren Dance of WWK brought this article to our attention.

FabTime welcomes the opportunity to publish community announcements. Send them to Jennifer.Robinson@FabTime.com.

Subscriber Discussion Forum

300 mm Lot Size, Cost of Cycle Time, and Productivity Reporting

Jim Hallas (Texas Instruments) sent in responses to several issues raised in the last newsletter:

"1) You should be able to safely tell Scott Mason that 13 (12 product + 1 pilot) and 25 (24 product + 1 pilot) wafer lots are settling in as the standard in 300mm. I don't know of anyone who is not using one of those two, with 24(25) being the most common.

2) To your next reader's question - my assumption is that (currently) the most tangible way to calculate the cost of cycle time is based on the fab's yield learning rate. For example, you might use something like the following methodology:

A. Assume the fab is fully loading at some level (e.g. 20K wafers out per month).

B. Assume initial values for avg. selling price per wafer, line yield, and chips/wafer.

C. Using the formula XX% yield x $YY per die sold x ZZ chips/wafer, calculate the revenue per year of a fab with some natural yield learning rate (say 8% defect density improvement per month).

D. Calculate the additional number of learning cycles you get in a year by reducing cycle time by 25%.

E. Calculate the increasing yield learning rate (say 12% vs 8%) that will give you XX number of additional chips - and therefore - addition revenue per year for the fab.

F. Subtract off the cost of the cycle time decrease efforts (new capital, people, etc) and you will have the resultant benefit.

3) Lastly, my opinion is that even if you use real time dispatcher or some similar product, you will not replace TAKT style charts (as Athena Fong asked) or shift move reports. My reasoning for this is that keeping the tools up and keeping them running is still based on human sweat rather than anything else - so the humans will continue to need the tracking and motivation to hit production goals. Even if we fab folks know very well what to run (via RTD), by watching production moves daily we can work to run that stuff FASTER."

FabTime Response:

Thanks for your message! We're always putting out these types of questions for reader feedback, and don't always get many responses. To get feedback on three of the questions from you is a big help, and I think will be valuable for our readers.

Regarding the cost of cycle time, I like your suggestion about using yield learning rate. Yield is well known to be the biggest controllable driver of wafer cost (equipment cost drives the wafer cost in a big way, but isn't as controllable). We're working on developing a more comprehensive model for cost of cycle time (like our previous spreadsheet models), and I think that your proposed methodology would be a great thing to include. My guess is that (at least once market conditions improve) the cost of cycle reduction efforts will be well covered by the benefits from additional revenue in this model.

Regarding your last point, about the continuing need for TAKT charts and shift move reports, I couldn't agree more! We originally focused FabTime around cycle time and WIP-based reports (since it is a "cycle time management system"), but we immediately had our customers asking for move-related charts. As you said: "humans ... continue to need the tracking and motivation to hit production goals." And I'm certainly in favor of providing any information that will help people in production "to run that stuff FASTER."

300 mm Lot Size (2) and Factory Size

Walt Trybula (SEMATECH) wrote: "Regarding Scott's question, the automated handling Fabs are favoring 25 wafer cassettes, while the non-automated handling ones will look at 12 wafer cassettes. A test wafer could be employed in the 13th spot. Regarding lot size, how many of the cassettes are included will need to be reevaluated based on the type of facility - DRAM, Logic, or ASIC.

A more important consideration is the size of the Fab. Historically, we have employed 5K wafer starts per week for a 200mm Fab. There are people considering going to 7K wafer starts for a 300mm Fab. There are major implications with this choice. One of which is that one 300mm Fab would be equivalent to 3.15 200mm Fabs. Of course, the leading edge Fabs will also employ more levels and the associated more processing steps as well as different processes.

Costs, cycle time, inventory, hot jobs, etc., all take on more importance as the volume of products increases. As the complexity of the circuit increases and the dimensions decreases, the manufacturing process may require more time than at looser tolerance geometries. There are a lot of other consequences that will impact manufacturing as we push through the 100nm barrier."

FabTime Response:

I think that your points about the size of the fab and related issues are also well taken. Personally, I think it's good news, in a way, because it means that despite the increased level of automation in 300mm fabs, there will be no shortage of interesting problems to examine. Of course, I don't have to manage a 300 mm fab, so that's easy for me to say.

300 mm Lot Size (3) and Relating Cycle Time to OEE

Peter Gise (Nanometrics) wrote: "Regarding 13 vs. 25 wafer FOUPs/lots - Motorola originally started the 13 wafer FOUP craze. Their thinking was that operators could still manually carry and load 13 wafer FOUPs (fully loaded 25 wafer FOUPs would be too heavy and unwieldy). However, most fabs realized early on that full automation provides the most efficiency and safety for 300mm wafer manufacturing. So virtually everyone is going to 25 wafer FOUPs. As far as the lots are concerned, the move has been toward single wafer lots, so the 25 wafer FOUPs may be loaded with any number of wafers up to 25. I think the 13 wafer FOUP is dead."

On an unrelated question, Peter also asked: "Have you done anything to incorporate Overall Equipment Effectiveness (OEE) in your cycle time models? It is possible to relate OEE directly to cost per wafer through various fab models."

FabTime Response:

Thanks for your response to Scott's lot size question. Three other people wrote in about the 13 vs. 25 wafer lots, but none of them expressed your view that the 13 wafer FOUP is dead. I think it's more interesting to have multiple viewpoints to write about, so I think that's great. All of you who wrote in know more about it than I do, so all I can really add to the discussion is to share it with FabTime's readers.

Regarding your question, I think that relating OEE to cost per wafer is straightforward, and makes a lot of sense. The better (higher) the OEE, the better (lower) the cost per wafer. Unfortunately the relationship for cycle time is not so straightforward. The reason for this is that cycle time increases with increasing equipment utilization. And OEE drives you to increase utilization (through the performance efficiency component, which tries to reduce standby time), which in turn increases cycle time (not better). Of course OEE also drives you to lower variability, and to reduce equipment downtime, both of which can improve cycle time. I think that one could relate cycle time to some components of OEE (increasing the quality and availability portions of OEE will improve cycle time), but not to the standard definition of OEE as whole. There is a version of OEE called Production OEE (defined in SEMI standard E79) that measures OEE only while product is in the area. This, I think, could be used to relate to cycle time. Certainly improving Production OEE would generally tend to improve cycle time.

However, the methods that I know of for estimating cycle time are easier to apply using the base components from which OEE is calculated, rather than a rolled-up number. Cycle time is essentially a function of input rate, service rate, availability, and variability (in arrivals, service, and downtime events). You need these lower-level inputs in order to get a meaningful estimate of cycle time using either queueing or simulation models. The reason you need the lower-level inputs is that improvements in different areas don't all have the same effect on cycle time (though they would have the same general effect on cost per wafer). Reducing the downtime percentage, and thus increasing the percentage of idle time on a tool, could have a big impact on cycle time. But the exact impact depends on where you already are on the cycle time vs. utilization trade-off curve. If utilization is already low, decreasing it some more won't have a big effect. But if it's above about 85%, then even very small changes can have a big cycle time effect.

So, in summary, I think that improving Production OEE will generally improve cycle time, and is certainly a good thing to do. However, I don't think that the OEE number alone provides enough information to develop any explicit relationships with cycle time. There may, however, be people who disagree with me - OEE is definitely not my area of expertise, and if you look through some of the past newsletter issues, you'll see that people have had differing views on the subject.

300mm Lot Size (4)

Ron Billings from SEMATECH also wrote in response to the 300mm lot size question, and said: "The SEMI standard 300-

mm wafer carrier is the Front-Opening Unified Pod (FOUP) which has a capacity of either 13 or 25 wafers (although only Motorola plans to use the 13-wafer option).

Most fabs will run full or nearly full 25-wafer FOUPs, but many fabs that have many products will have multiple products on the same FOUP (typically six 4-wafer lots). Regularly transporting fewer wafers in each FOUP overtaxes the material handling system."

FabTime Response:

Thanks for your response to the lot size question. We've had several others, but your seems to me to be very definitive, giving SEMI's viewpoint on the 13 vs. 25 wafer question. I also appreciate how you've addressed the important issues of how full the lots will be, and mixing of different products in the same lot.

Modeling Operator Impact

Lee Schruben (University of California - Berkeley) wrote, in response to Hermann Gold's remarks about the impact of operators on best-case cycle time, to ask: "Can you tell me how I can find the latest info on how folks are dealing with modeling Operator impact? I assume that they are simulating but adding operators can really slow down the runs."

FabTime Response:

I have looked through the references that I have on what people are publishing about modeling operator impact, and I think that it is mostly simulation, although some (like Hermann Gold's paper mentioned in the last issue) have applied queueing models, and others non-linear programming models. Tefen has a queueing-based staffing model, I believe. My opinion is that you can modify queueing models to capture some of the relative effect of needing to seize an operator resource. However, if you want to look at detailed operator behavior, or know absolute cycle times, you still have to go with simulation. And even that's not perfect, because most simulation models treat operators like tools, just another resource that you seize, and capture neither the intelligence nor the additional variability of humans. But you know all that.

If any of our subscribers would care to share your thoughts on modeling operators, we will include them in the next issue. Please note that on this, and all topics, you can have your name included in or withheld from the published topic - we never include your name without your permission.

Modeling Cycle Time and WIP During a Ramp

Another subscriber, from a TFT-LCD maker, asked: "Is simulation the only way to predict cycle time and WIP level change in the condition w/ no history data? I mean in a ramp up fab." He also added to his message the explanation that TFT-LCD fabrication follows a process very similar to wafer fabrication, but shorter and less complex.

FabTime Response:

You can normally predict cycle time and WIP levels using either simulation models or queueing models. Simulation models are more detailed, and can give more realistic estimates of cycle time if you have sufficient data. Queueing models (as used in our characteristic curve generator spreadsheet) are mathematical models used to give estimates of long-range performance. They are less detailed than simulation models, but run much more quickly, and are good for getting relative comparisons of performance, rather than absolute values. They are less appropriate in a ramp situation, where things are constantly changing (because they by their nature are estimates of long-term, steady-state behavior).

I think that you could put something together in Excel using queueing formulas, especially if FabTime augments our characteristic curve generator to handle tool-groups with multiple tools (something planned for early next year). Because your process is shorter and less complex than semiconductor wafer fabrication, combining the queueing estimates for individual tool groups to gain overall cycle time estimates isn't prohibitively complex. However, because of the ramp situation, I think that simulation is probably the most appropriate solution for you.

Here again, perhaps other subscribers have something to add on the subject of estimating cycle time and WIP during a ramp.

Productivity Reporting

Allan Ravitch of STMicroelectronics wrote to us in response to Athena Fong's question/comments last month about useful productivity reports. He said: "Part of the project I've been involved in relates directly to this reader's question. By breaking down shift/daily goals to one hour increments and providing a two way system for fab personnel to communicate with the system that generates the goals, (in this case AutoMod) we have built an in-house way to track and react to short term goal achievement and gaps from the forecast and actual results. We have also built a way to categorize and archive for evaluation purposes these gaps for analysis so we can understand problems and correct them.

The simulation updates every 30 minutes in our fab and allows for up-to-date information on goal adherence and also assists in globalizing communications between manufacturing units so that the relationships between the units are better understood and they, in kind, work closer to achieve the entire fab goals for their shifts."

FabTime Response:

I think that comparing performance to short-term goals makes a lot of sense. Your in-house tracking system seems to share some similarities with FabTime's software. Using simulation to set the short-term goals is something that we haven't done yet, but have been considering. We look forward to seeing your paper on the subject. (Allan has a paper in progress.)

Industry Definition of "Loading"

Another subscriber asked: "I have one question. Can you point me to some papers/references to the definition of loading? I am trying to get people here talking the same language and I hope it is the same language as the industry."

FabTime Response:

I think that the definition of loading is a known problem - or at least a known area of ambiguity.

The definition that Frank and I use is:

Capacity loading percentage = 100 * Input Rate / Actual Max Processing Rate, where

Actual max processing rate = Maximum rate at which a factory, tool group, or operator group can actually process lots or units (i.e. the Input Rate at which Free% is zero). Assumes product mix held constant.

These definitions are from the Factory Explorer® user manual, and have been in use in any papers that we've written, including our work with Infineon and Seagate. Note that loading, by this definition, is not the same as utilization or busy percentage. If you have a tool that's down 50% of the time, busy 25% of the time, and idle 25% the time, then that tool has a capacity loading of 50% (because it's processing for one-half of the time that it can spend processing). However, the tool is busy (either processing or down) for 75% of calendar time.

Our definition of capacity loading percentage is analogous to the SEMI E79 standard definition of operational efficiency (the faction of equipment uptime that the equipment is processing actual units). E79 is the SEMI standard for definition and measurement of equipment productivity. There are other productivity metrics defined (including OEE), but nothing that SEMI refers to as "loading".

The SEMI E10 standard for definition and measurement of equipment reliability, availability and maintainability defines equipment utilization, but again has nothing called "loading." Operational Utilization is the percentage of productive time during operations time, where operations time includes all time except for factory non-scheduled time. This is distinguished from Total Utilization, which is productive time divided by total time.

None of this really gives what I would clearly describe as an industry standard definition. Perhaps some of our readers will have something to contribute on the subject.

Cycle Time for Wafer Production

Jan Krivan (Terosil) asked: "Do you have any information about cycle time at any wafer house / wafer production facility? We produce wafers from 4" to 6", polished or with epi layer."

FabTime Response:

I'm afraid that I don't have any information at all about CT at wafer production houses. We do have a few subscribers from other wafer production companies, however, so I can ask the question in the next newsletter, and see if anyone has anything that they can share on the topic.

Calculated System Variation in Characteristic Curve Generator

Mark Spearman, of Factory Physics, Inc. (one of the authors of the book Factory Physics, which we have referenced extensively), wrote in response to a question in Issue 2.8 about the derivation of the formula for system variation used in our Characteristic Curve Generator (from Issue 2.7). The formula that we used was:

CV = Cs + (1+Cr)*RTR*(1-Av)

Mark wrote: "Actually, the formula is equation 8.6 in Factory Physics (almost). It should be

CV = Cs + (1+Cr)*RTR*Av*(1-Av)

if we are talking about the same thing. Also, the coefficients, CV, Cs, and Cr are the SQUARED coefficient of variation, not the coefficient of variation. SCV0 is the "natural" variation that cannot be explained. So the final equation should be:

CV^2 = calculated system variation = Cs^2 + (1+Cr^2)*RTR*Av*(1-Av)"

FabTime Response:

In the original derivation (in Issue 2.7), we did use the squared coefficient of variation for these variables (where the squared coefficient of variation is the variance divided by the mean squared). However, we mis-defined this as the coefficient of variation, instead of the squared coefficient of variation, and used the non-squared version (incorrectly) in our spreadsheet. We have gone back and changed this in the original issue, and modified the Excel spreadsheet accordingly.

We've also modified our formula to match the Factory Physics formula as listed above. Note that the only other difference in the two formulas lies in an additional Av (availability) multiplier in the Factory Physics formula. This will move up or down any curves that you previously developed, but any relative comparisons between variables should remain very similar. You can find this formula, with discussion, in the second edition of Factory Physics, as equation 8.6 in section 8.4.2. If you have the first edition, you'll find a similar formula as equation 8.7. The difference in the earlier edition is that it only applied for exponential repair time distributions. Instead of (1 + Cr) it had had 2 for a multiplier (because Cr for an exponential repair distribution = 1, and (1 + Cr) thus equals 2.)

We are grateful to Mark for bringing this revised formula to our attention, especially as we did not previously have a very solid reference for the formula. You can download a revised version of the characteristic curve generator spreadsheet from our website, at www.FabTime.com/charcurve.htm.

Calculation of Product and Factory Line Yield Values

Another subscriber asked: "What is the common way of calculating product line yield and overall fab line yield? (If one of the variables is the number of operations/steps for the product, do we use the TOTAL number of steps for the product or just the active ones for the time period we're interested in?)"

FabTime Response:

Calculation of line yield is one of those things in a fab that seems simple, but is more complicated than it looks. I talked with Frank about this, and we actually don't believe that there is a standard way to do this. Our best guess is that people are doing something like the following:

For a give time period (previous week, say):

OpnYield(Prod,Opn) = (MvsOut(Prod,Opn))/(MvsOut(Prod,Opn) + Scraps(Prod,Opn))
(If no moves for the week, then set OpnYield(Prod,Open) = 1)

LineYield(Prod) = OpnYield(Prod,Opn1) * OpnYield(Prod,Opn2) * ... for all ops on the route for Prod.
MvsOut(Prod) = Sum_Opn {MvsOut(Prod,Opn)}
MvsOut(Fab) = Sum_Prod {MvsOut(Prod)}
FabYield= {Sum_Prod [LineYield(Prod) * MvsOut(Prod)]} / MvsOut(Fab).

So the overall Fab yield is a weighted average (by moves) of the individual product line yields...

We confirmed this method with a friend who has worked in yield improvement, but if any readers have a better suggestion for calculating yield values, we would definitely be interested in hearing it.

Explicitly Including Cycle Time in Capacity Planning

Introduction

The traditional capacity planning method described last month accounts for cycle time implicitly, through the use of a capacity loss factor or factors. The larger the cycle time factor the lower the cycle times will be, on average, for the fab. What this doesn't tell us, however, is how low the cycle times will be. If we use 15% slack capacity in planning tools, can we get the cycle times below 3X? Below 2X? It would be great if there were a nice, simple relationship like that. Then we would know exactly how much it would cost to have lower cycle times, and understand the trade-offs.

Naturally, it's not that simple. A fab is a complex dynamic environment. Cycle time depends on many different factors, not just equipment loading (although equipment loading is probably the factor with the largest impact). Also, the long lead time for capacity procurement means that by the time tools are in place and qualified in the fab, process flows and product mix have probably changed, so that the loading isn't exactly what was planned in the first place. There are, however, ways that we can develop a more clear understanding of the relationship between the capacity planning decisions and cycle time. These will be discussed in this article.

Integrating Targeted Cycle Time Reduction into the Capital Planning Process - Seagate Technology

In 1998, Frank Chance and I worked with Navi Grewal, Al Bruska, and Tim Wulf of Seagate Technology's recording head wafer division on a project to integrate cycle time reduction into the capital planning process. In this project, we used static capacity analysis to identify an initial equipment set with little slack capacity, and then we used simulation to identify the critical tool groups where tools should be added to meet overall cycle time goals. We found that this approach generated less expensive toolsets than the traditional method of simply including a global slack capacity value, along with more predictable cycle times. This study used the Factory Explorer® (FX) capacity analysis and simulation tool for all runs. FX was originally developed by Frank Chance, but is now wholly owned and distributed by Wright Williams & Kelly. The study used the following heuristic:

1. Build and validate an initial model, with expected process flows, product mix, tool types, and equipment downtime characteristics.

2. For the planned start rate, run capacity analysis to create a base model with minimum cost tool set (using the relatively low value of 10% for slack capacity per tool group).

3. Use simulation to estimate base cycle time and total queue delay time contribution by tool group.

4. For each of the top five tool groups in the base model (ranked by contribution to queue delay):
   a) Starting with current base model, add one tool to the selected tool group to form a candidate model.
   b) Use simulation to estimate the cycle time for the candidate model.
   c) If the new cycle time is statistically significantly lower than the base cycle time, compute the ratio of cycle time reduction to tool fixed cost.

5. For the candidate model with the best (largest) reduction per dollar ratio, record the tool added and replace the base model with the candidate model.

6. Go to Step 4 or terminate (a) if the budget limit is reached or (b) if no candidate model results in a statistically significant reduction in cycle time.

This method resulted in recommended equipment sets that saved $4M to $9M in capital expenditure for Seagate (for different planned volume levels during a ramp). You can read more details of the method in the full paper on this study, available from FabTime's website at www.FabTime.com/abs_SiemWSC98.htm.

This method is simply a heuristic, and is not guaranteed to produce a toolset that is optimal in any strict sense. The reason that this method generates lower-cost toolsets than the more traditional method of applying a global capacity loss factor is simple - not all toolgroups have the same impact on cycle time, even if they have the same equipment loading. For example, one-of-a-kind tools have a disproportionately high impact on cycle time (as discussed in newsletter Issue 1.8), as do large batch tools, and particularly unreliable tools. This method allows you to identify tools that are relatively inexpensive, but contribute significantly to overall cycle time. By adding capacity at such tools first, cycle time goals can be met in a more cost-effective manner.

Longer-Term Impact of the Study on Seagate

Said Navi Grewal, the primary author of the original study: "This methodology helped us quantify the impact of single path tools on fab capacity and cycle time. Also, it brought to the forefront the effect of support tools such as inspection stations, which were very sensitive to rework rates or recipe set up changes. Tools later in the process flow, like ovens and microscopes, were typically overlooked in the slack spreadsheet analysis. However, over time Seagate started appreciating the impact these tools had on managing utilization of more expensive tools (due to data feedback loop constraints). The factors explained above were termed as qualitative issues. Through simulation we were able to quantify the impact of the factors. In summary, this changed some of the capacity planning methods for the long-term."

Comparison to the Traditional Method

The above approach for targeted cycle time reduction through capital planning can generate more cost-effective toolsets than the traditional approach of globally applying a slack capacity variable into a static model. It also lets you target specific cycle time goals, rather than just knowing in general that larger slack capacity factors will yield lower cycle times. However, this method does require considerably more work. It requires building a detailed capacity and simulation analysis model, and sufficiently validating it to give confidence in the relative cycle time contributions of the different types of tools. It also requires repeated simulation runs, which are much more time-consuming than static capacity analyses, as well as statistical analysis of the output. This method may also be less robust to changes in process flows or product mix than the traditional, equipment loading-based method. However, given the ever-increasing cost of semiconductor equipment, I believe that the method is worth the effort in at least some cases.

Simplifications

There are compromise solutions to this problem that avoid the need for building detailed simulation models. The idea is to try to account for some of the things mentioned in the above approach, while still using spreadsheet models. Here are some suggestions:

- Vary the magnitude of the slack capacity values according to the cost of the various toolgroups. That is, include less slack capacity on the more expensive tools, and more on the less-expensive tools. I have seen at least one company that does this routinely.

- Vary the magnitude of the slack capacity values according to the reliability of the various toolgroups. Include more slack capacity for less reliable tools.

- Do not allow one-of-a-kind tools, or at least do not allow relatively inexpensive one-of-a-kind tools, no matter how lightly loaded. Many companies already do this.

■ Include more slack capacity for large batch tools, at least relatively inexpensive ones, or batch tools that are required to process many different recipes (that cannot be processed together). This may be difficult to do, due to layout constraints, and is the hardest to predict without using simulation.

None of these methods allow you to shoot for specific cycle time targets, but they can help to generate more cost-effective and/or lower cycle time toolsets. You might wish to use a simulation or queueing model to validate the results, especially at first, until you develop some useful guidelines that apply to your particular fab.

Related Work

This article summarized one method of including cycle time explicitly in capacity planning, and outlined possible extensions. Other methods exist. You could, for example, include simple queueing formulas right in your capacity planning spreadsheets, to estimate the expected cycle time contribution of the different tools, based on their equipment loading and downtime characteristics (as in the characteristic curve generator that we included in Issue 2.7). Researchers at IBM's T. J. Watson research center developed a factory-level queueing network model that could be used for this type of analysis (see the second reference below).

Further, IBM researchers developed a decision-support system called CAPS (see the third reference below), which uses linear programming for strategic planning of semiconductor manufacturing capacity. According to Dr. Stuart Bermon of IBM, "CAPS takes cycle time considerations into account in the form of a parameter termed the "WIP TURN MODIFIER" (WTM) ... The WTM is a factor (>= 1) defined by product and time period that effectively multiplies the product start volume to take cycle time considerations into account. Previous to the introduction of WTMs, (IBM) Burlington had used "Tool Contingency Factors" that provided for idle time on a tool by tool basis." Thus the WTMs appear to account for cycle time more explicitly than the prior contingency factory approach (a type of approach that was discussed in the last newsletter article).

Finally, you could examine the relative cycle time contributions of different tools in an existing fab, to identify toolgroups where excess capacity could be most useful in improving cycle time, and develop statistical models for when to over-ride the global slack capacity value for a toolgroup. The people at the Agere systems fab in Madrid did some nice work in this area, before that fab was closed. See the Bonal reference below.

Conclusions

This article summarized one method for explicitly including cycle time in the capacity planning process, based on a project from Seagate Technology. The method involved using simulation to estimate the cycle time of candidate models, and adding tools on the basis of greatest cycle time reduction per dollar of fixed cost. The main point to remember from this study is that other factors besides equipment loading have an influence on the cycle time contribution of individual toolgroups. Considering those other factors can allow you to plan for more cost-effective toolsets.

Further Reading:

1. N. S. Grewal, A. C. Bruska, T. M. Wulf, and J. K. Robinson, "Integrating Targeted Cycle-Time Reduction into the Capital Planning Process," *Proceedings of the*

1998 Winter Simulation Conference, Washington, DC, D. J. Medeiros, E. F. Watson, J. S. Carson, and M. S. Manivannan, eds, 1005-1010, 1998.

2. D. Connors, G. Feigin, and D. Yao, "A Queueing Network Model for Semiconductor Manufacturing," *IEEE Transactions on Semiconductor Manufacturing*, Vol. 9, No. 3, 412-427, 1996. This paper includes a method for doing tool planning for semiconductor lines. The method is based on a marginal allocation procedure that uses performance estimates from a queueing network model to determine the order in which to add tools to the line. The method can be used to determine the number of tools needed to achieve a target mean cycle time at minimal cost.

3. S. Bermon and S. J. Hood, "Capacity Optimization Planning System (CAPS)," *Interfaces*, Vol. 29, No. 5, 31-49, 1999. CAPS is a decision-support system based on linear programming for strategic planning of semiconductor manufacturing capacity. CAPS finds the volume mix of products to maximize profit, constrained by the existing tool capacity, or identifies the tool capacity required to manufacture a specified mix of products. This article was a finalist for the 1998 INFORMS Daniel H. Wagner Prize for Excellence in Operations Research Practice.

4. J. Bonal, M. Fernadez, O. Maire-Richar, S. Aparicio, R. Oliva, S. Garcia, B. Gonzalez, L. Rodriguez, M. Rosendo, J.C. Villacieros, and J.Becerro, "A Statistical Approach To Cycle Time Management," *Proceedings of the 2001 Advanced Semiconductor Manufacturing Conference (ASMC 01)*, Munich, Germany, 2001. This paper describes the method used in the fab of Agere in Madrid. The method is based in the use of Exponentially Weighted Moving Average for cycle time target setting to machine level.

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■ Navi Grewal (formerly of Seagate Technology) collaborated with FabTime on the writing of this article. He offers a perspective on the longer-term impact of the original study at Seagate, and a more "inside" view than we had as consultants working on the project.

■ Gerry Feigin (SmartOps) provided us with the second reference above, and referred us to Stuart Bermon (IBM) for information about some related follow-on work (the CAPS project - the third reference above). Stuart explained how CAPS takes cycle time into account, through the use of the WIP turn modifier. The WTMs are not discussed in the published article, and we are grateful to Stuart for taking the time to bring them to our attention.

■ Javier Bonal (formerly of Agere Systems) sent us the fourth reference, one of several papers that he has shared with us over the past few years on subjects related to cycle time and capacity planning.

FabTime Recommendations

Factory Physics Consulting

One of our new subscribers this month is Professor Mark Spearman, one of the authors of the text Factory Physics. Mark has established a consulting firm for factory physics consulting, Factory Physics Inc. The website, www.factoryphysics.net/factoryphysics/, contains a description of the company's I4 Factory Physics Implementation Strategy, as well as available training courses and software (available only to consulting and training clients). Supplemental textbook materials and software are also available for academic users. If you are interested in the Factory Physics methodology, and looking for help implementing it, Factory Physics Inc. could be a good place to start.

IBM Technical Reports Online

IBM maintains a searchable repository of references to all Technical Reports (at least those published since 1990) at domino.watson.ibm.com/library/CyberDig.nsf/Home. Not all of the reports are available for download, especially the older reports. If the report was later published in a conference proceedings, for example, IBM no longer makes the paper available. However, this repository is an excellent place for reviewing newly written IBM research reports, and for obtaining copies of papers that were never published externally.

Quick Info Software Utility

Quick Info is a freeware program distributed by Contact Plus Corporation. It's a reference lookup tool for three things: U.S. telephone area codes and time zones, international direct phone-dialing codes and time zones, and Internet domain suffixes. Personally, I mostly use it for looking up telephone area codes - you just type in the area code, and the program shows you information about that code (e.g. the state, and major cities in the area code). The program is free (no annoying pop-ups or registration, it's true freeware), focused on a very specific problem, and when you need it it's very useful. You can download it from www.contactplus.com/products/freestuff/quick.htm.

Optimization Online

Optimization Online is a repository of eprints about optimization and related topics. Submissions to Optimization Online are moderated by a team of volunteer coordinators. Coordinators check submissions for correctness of author-title-link information, but make no claim about quality or correctness of the reports. The site does not include very many application-related papers, but there are a few (including an October 2001 IBM report about "Robust Capacity Planning in Semiconductor Manufacturing." We're bringing this site to your attention because we think that the idea of online paper repositories, targeted to specific communities, is a good one, and we hope to see more of them. You can sign up to receive an email notification each time a new issue is released to the web. There are currently about 16 monthly issues online. The website is located at www.optimization-online.org/index.html.

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