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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Table of Contents

- Welcome
- Community News/Announcements
- Subscriber Discussion Forum
- Main Topic – In-Depth Guide to Operators and Cycle Time
- Recommendations and Resources

Welcome

Welcome to Volume 4, Number 6 of the FabTime Cycle Time Management Newsletter. This month we have an announcement about a new Fab Managers Forum to be held in association with Semicon West. Subscriber discussion topics for this month include a response to last month's article about arrival process variation, a question about tri-metal processing, and a question about calculating metrics related to on-time delivery and number of moves. Discussion was very light this month, perhaps due to summer vacations, but we hope to hear from more of you in the near future.

This month's main article is about operators. We noticed, on reviewing the past newsletter issues, that we have had quite a bit of discussion concerning operators over the past two years. It is by far our most popular topic. This discussion has been spread out across many different newsletter issues. We thought that there would be benefit to collecting and summarizing it here in a single article. We hope that you will agree. We also summarize FabTime's thoughts on the operator-related questions, and highlight industry resources that we know of related to operators (software, papers, etc.).

Thanks for reading!—Jennifer

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Community News/Announcements

Semicon West - Fab Managers Forum

Semicon West will take place the week of July 14th. This year the show will include a number of new programs and events, including one that we thought would be of particular interest to FabTime newsletter subscribers. Thursday, July 17th, there will be a Fab Managers Forum held at National Semiconductor in Sunnyvale. The Semicon West website (www.semi.org/semiconwest) says: "SEMI and International SEMATECH will host a new event—the Fab Managers Forum. With the theme "Current and Future Trends in Semiconductor Manufacturing," the forum is an event where fab managers and their staff, as well as executives and professionals from semiconductor equipment and materials companies, can learn about the latest trends and strategies in improving semiconductor manufacturing productivity. Plan to attend and discuss critical issues with peers and suppliers." The cost to attend is $295 if you pre-register by July 7th, and $395 afterwards. FabTime is not participating as a speaker, but I (Jennifer) do plan to attend the meeting.

Also, if you will be attending Semicon West and would like to meet with FabTime to see a demo of our web-based cycle time management software, just email Jennifer.Robinson@FabTime.com to make arrangements.

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

Subscriber Discussion Forum

Arrival Coefficient of Variation

Daren Dance wrote in response to last month's article about arrival variability. "I noticed years ago that the CV of arrival for lots with yield problems was generally much higher than normal production. I attempted to use this information to better understand scheduling delay risks for short run products. I also noticed that once a lot has been delayed, it will have a higher probability of being delayed at subsequent processing steps. This is yet another hidden cost of yield variation."

Tri-Metal Processing

We received this inquiry from a San Jose-based fab. "Are you aware of anyone overseas that does Tri-Metal processing for wafers??" Send responses to Jennifer.Robinson@FabTime.com, and we will pass them along.

Calculating OTD and Number of Moves

An anonymous subscriber wrote: "There are two issue I'd like to try to explore through you. Both of them are very much related to CT management and I'm sure many of your readers will also find them interesting. The first issue is OSD (On Schedule Delivery) or OTD (On Time Delivery) as it is sometimes called. This is a critical index representing a Fab's ability

to supply the goods on time to its customers. From Benchmarking, it seems that the methods used to calculate this parameter are very subjective. The output is usually a number between 0% to 100% but the calculation method behind it can vary significantly between fabs. I'll be glad to hear from you and/or your readers if there is a convention or Standard for calculating this very important parameter. The second issue is regarding the concept of "Move". Currently we are joining a set of unit steps into a group called move. Usually a Move includes a major process such as Etching, a step such as Rinse, and an Inspection step. We only "count" One Move for each Wafer passing the set of unit steps. As far as you know, is this conventional/popular and what are the Pros/Cons using this method. Again, I'll be glad to hear the readers thoughts on the matter."

FabTime Response: Our impression is that people are moving towards smaller "move" granularity than what you describe (single move for Etch, etc). The disadvantage of smaller granularity is more transactions to enter, but the big advantage is better visibility -- into where WIP is sitting the longest, etc. In our software we count each operation move out as a move as the customer has chosen to define the operations in the fab Manufacturing Execution System (MES). We would be interested to hear how subscribers choose to quantify OSD and OTD.

In-Depth Guide to Operators and Cycle Time

Introduction

In looking over the past issues of this newsletter, we observed that we have had a considerable amount of subscriber discussion related to operators. This discussion has primarily fallen into two categories: 1) operator modeling/planning and 2) operator management (including dedication, cross-training, and performance evaluation). The first category concerns understanding how many operators will be required, and how they will impact cycle time and throughput. The second category concerns managing operators once staffing levels have been determined, to minimize cycle time and maximize throughput. In this article, we will summarize the subscriber discussion to date on operators, bringing it into one place, instead of scattered across two years of newsletter issues. We will also summarize FabTime's thoughts on the operator-related questions, and highlight industry resources that we know of related to operators (software, papers, etc.).

Background / Subscriber Discussion Thread

We have mentioned operators many times in this newsletter, as a contributor to wafer fab variability, as the people making short-term decisions about loading batch machines, etc. However, more specific discussion of operators began in Issue 2.9 (late 2001), when Hermann Gold (Infineon Technologies) wrote in response to an

article about setting goals for wafer fab cycle time. Hermann wrote:

"With respect to the last FabTime Letter my hypotheses on operator impact implies that the expectation of the best X-Factor is (1+alpha/2) X, where alpha is the variability of the Fab $(c_a^2+c_e^2)/2$. It does not contradict that 1X is the absolute best theoretical, but it might be an interesting notion in this context."

FabTime responded to this by making available a paper on human/machine interference that Hermann wrote (see details under Further Reading below). Lee Schruben (U.C. Berkeley) responded to Hermann's comments by writing in Issue 2.10:

"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 included some thoughts on this, based on what we had seen in published papers, and asked for other subscribers' comments on operator modelling. This discussion of operator modeling inspired Sihar Snir (Tower Semiconductor) to ask, in Issue 3.1, about operator performance evaluation:

"There's one major issue we've been dealing with lately (naturally) and that's the quantity of operators needed for our current activity level. Currently, we're using "Moves per Operator" as the major performance measure but I've also seen other Fabs use "Photo Layers per Operator". In addition, defining what's commonly used as the "Number of Operators" is not trivial. Some Fabs use only actual Operators, some also include the Support Groups, Process Technicians, and others. What I wanted to find out is what are the most widely used Performance Measures in the industry regarding Human Resource to Activity relations. I believe this issue is directly impacting Cycle Time (and I'll be glad if you could elaborate on that too) but I'm definitely not looking for another Staffing Model."

FabTime did not have any information on operator performance evaluation and staffing levels, and we posed it as a question to our subscriber base.

We did not receive any subscriber responses immediately to either of the above questions (from Lee Schruben or Sihar Snir). However, a few months later, in Issue 3.4 (mid-2002), Rick Alexander of AMI Semiconductor submitted some detailed comments regarding the benefits of tool dedication in some circumstances. Meanwhile another (anonymous) subscriber asked about staffing levels:

"As we consider increasing staffing at our plant due to increased demand for our product, I have been mulling over specific ways to justify operator headcount increases. There are several ways you *could* quantify the optimal number of operators (based on inventory or # tools) but I was wondering if you know of any research or papers out there that address this issue... Just curious what the experts in the industry say about this issue. So far, the decision for determining optimal headcount seems to be more of a guess, rather than any type of mathematical model..."

Responding to both Rick Alexander's previous comments on tool dedication, and the previous month's question about planning for the number of operators, Douwe van Engen (Philips Semiconductors) wrote in Issue 3.5:

"Now we are struggling with the fact that there is a trend going on in our factory to make the operators more and more multiple employable (autonomous groups). This is not limited to make them multiple skilled for operations, but also for activities as simple preventive maintenance, making of progress reports and dispatch list, and training of other operators. It feels that those extra duties will have more management attention than moving of lots. The question we are asking ourselves is: "how far can you go with making the operators multiple employable, without losing the benefits of multiple skilled operators in terms cycle time (lower variability). Is there an analogy with the example of Rick Alexander in FabTime Cycle Time Management Newsletter Volume 3, Number 4? Do you know what trend is going on in other semiconductor factories with respect to this topic? Hopefully you can help us solving this dilemma."

At this point, it seems, questions about

operators had been asked enough that people started to respond. Guido Dietz of Infineon Technologies wrote in response to the question about modeling operators in Issue 3.6:

"I have got an interesting addition to your answer concerning Operator Modeling. There was a presentation on this year's ASMC in Boston (attached). This paper takes similar approaches (capacity, queuing, and simulation) seen in Factory Explorer, Raviv 1995/ TEFEN, AGI, and references in the paper but details on implementation of these methods. The technology is not new but the readers will benefit from seeing how these methods were implemented in a fab." (See the reference below under Further Reading by Chen and Dabbas.)

Then, in response to Douwe van Engen's question about how people are handling operator dedication/training, Sanjay Rajguru (National) wrote the following in Issue 3.7:

"At National, Texas, our plan is to get the operators involved not only in performing routine PM's but also dispositioning lots (minor engineering duties). Our rationale is that this will reduce variability since the lack of technician availability causes more variability."

FabTime followed up on the staffing discussion by asking, in Issue 3.8, a survey question concerning the number of different operator certifications per operator that was typical at different fabs. We included the results in Issue 3.9, which is available on FabTime's Amazon zShop (http://www.Amazon.com/shops/FabTime). FabTime next wrote the main article in Issue 3.9 about the impact of staffing levels on cycle time. Our closing question in that issue was:

"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?"

This time we received a slew of responses, including more questions, and continuing over the next couple of issues. We're going to reproduce the subscriber remarks here, without FabTime responses. FabTime's thoughts will then be summarized in the following sections.

Issue 3.10 - A. An anonymous subscriber wrote:

"1. Do you measure the percentage of time that your tools spend waiting for operators? Currently, the only way of measuring operator performance in my fab is to calculate the turns (moves/wip) of a certain tool cluster and the fab as a whole. It sounds pretty sad, but we did experiment with measuring the amount of time a lot spends waiting at an idle machine. However, the following problems made this impractical and the data inaccurate:

(a) Many tools are registered within the MES to run a certain step. However, simultaneous resources, like reticles, have to be available too. E.g. 8 lots are waiting to run GP photo. Theoretically, more than one stepper can run these lots -- however, if there is only 1 reticle for GP, then 7 lots will need to wait while the first one gets processed. If we were to download data directly from the MES, it would appear that those 7 lots are idling away in front of idle steppers -- when in fact, they are not. To consider the availability of reticles takes additional resources.

(b) Tool dedication for certain steps.

(c) Queue time constraints between steps. e.g. between a cleaning step and furnace operation. This forces lots to wait in front of an over-capacity wetbench if the furnace (2 steps away) is busy.

I'll admit that with enough effort, the time tools spend waiting for operators can be studied. It is by no means a trivial exercise and appears prohibitive with the current resources we have. But it is in the works. Anyway, is there a simple approach how other fabs measure their operators' performance?

2. Do you include operators in your capacity and simulation models? No. However, we are looking into the impact of lot travel time (between tools) to CT. For your information, we do not use AGVs for lot transportation, but rely on manual operator movements. Therefore, operator efficiency is doubly critical. Any suggestions?

3. Do you think operator loading levels contribute to CT in your fab? Definitely."

Issue 3.10 - B. Another anonymous subscriber wrote:

"Interesting dialog about operator availability. However, in a "state of the art" fab, the cost of direct labor is so small compared to the depreciation, no one ever skimps on direct labor, so the availability issue doesn't come up much."

Issue 3.10 - C. Another anonymous subscriber wrote:

"1. We do measure idle time on the tools.
2. We currently have operators in our capacity model, and are shortly going to be adding operators to the simulation model, though this is a long and arduous task...
3. Operator loading levels definitely contribute to cycle time in our fab, especially when the fab loading levels are high. This is the primary reason for adding operators to both static and dynamic models, so that we can understand the impact of cross-training, certification, and operator saturations for temporary WIP build-ups and long-term bottleneck tools. As a secondary driver for this effort, we also need to be able to justify maintaining operator levels in a slow period, increasing operator headcount in an upturn, etc. with accurate estimates of the metrics folks care about, like cycle time and outs, rather than stating an increase or decrease in "capacity"."

Issue 3.10 - D. Robin McAuslan of National Semiconductor:

"We've not managed to measure accurately our real wait operator time, but we have started moving towards this. The problem is typically that usually this circumstance occurs because the operators are running other tools. On one tool set, which has recently been fitted with a customised Station Controller, we have programmed in the ability to log automatically to no operator if a batch has completed processing but Workstream has not been logged to 'production-end' AND there is inventory waiting. This is a very hot topic for us at the moment.

I introduced operators into our ManSim model some 6 or 7 years ago; it was the first thing I did once I learned how to use the model and it paid instant dividends. It suggested a rebalancing of the fab headcount (from area to area and shift to shift), and where best to increase skills. Net result was a 30% improvement in cycle time achieved very quickly. We've kept our full complement of operators in the model now that we're using ASAP. We model each shift, breaktimes, absence and holidays, and personally I wouldn't be without it. As you stated, it is impossible to cover every aspect of the operators day, like telephone calls to engineers, impromptu training sessions etc, so to allow for that you need a max load rule on the operator. Typically I would aim for 70% as a guide. We interpret this data to create training plans for each shift/area, so the linkage between modelling and Training is key. If time ever allowed I would also model maintenance personnel, as this can be equally important from a planning point of view.

And yes, Operator loading levels undoubtedly contribute to cycle time in the fab!"

Issue 3.10 - E. Another anonymous subscriber wrote:

"In regards to the question on operator staffing impact and whether or not we measure the percentage of time a tool is idle due to staffing issues. We do measure this time. Anytime a tool is unable to run because of the inability to staff it, it is logged down to a "No Operator" code. That time is rolled up into Standby Time since we feel we can impact and gain that time back. However, we wanted specific visibility to that element of Standby to use as leverage to address staffing shortfalls."

Issue 3.10 - F. David Chia of Chartered Semiconductor Manufacturing

"Along the discussion on operator staff impacting capacity, I have a question on "what is the typical wafer moves per operator expected?" There is a measurement on how we staff operators verses number of equipment etc etc."

Issue 4.01 - A. Phil Fontes of NEC Electronics

Philip Fontes of NEC Electronics wrote not to address the specific questions that we asked in Issue 3.09, but because he had questions about two aspects of last month's article. First, he raised the point that the values that we gave in our example as the M/M/3 queueing results (for the case without operator constraints) did not quite match what one would get from entering the values in the Queueing ToolPak spreadsheet add-in that we recommended. The reason for this discrepancy was that we did not use the Queueing ToolPak for this example, but instead used our Operating Curve Generator spreadsheet. There is a slight difference in the approximations used by these different tools, and we also rounded slightly to use a value already included in our operating curve spreadsheet. So, we thank Phil for his careful attention to the results, and we wanted to explain this here, in case anyone else was puzzled.

Phil also raised this issue: "I am perplexed with the

notion of "...forced idle time drives up equipment utilization." That seams so counter-intuitive, because you don't get more wafers out when your tool sits idle due to operator unavailability to load/unload lots. People usually equate increased productivity with higher tool utilization. Of course, the only way to get a higher ratio is to take some time out of the denominator: (Productive Time) / (Productive Time + Standby Time.) So, the point of contention becomes, "why don't you include forced idle time in Standby time?" Since Line Maintenance has the responsibility of keeping the tools "available", and Production has the responsibility of keeping the tools "staffed", it seams unfair to skew [increase] utilization numbers when Production has not made greater use of the tool's "available" time."

Issue 4.01 - B. An anonymous subscriber wrote in response to David Chia's question

"We find our Operator productivity is heavily influenced by the % Utilization of our Fab capacity. We typically plan Operator requirements (and track overall average productivity) based on Mask Alignments per Operator per Day. I've converted this to equivalent Lot Step Moves per Operator per Shift.

Operator Productivity Goals Table

% Utiliz.	Aligns/Op/Day	Moves/Op/Shift
25%	20	23
49%	32	37
70%	38	45
86%	42	48
100%	43	49

Aligns/op/day:
= Total daily Mask Alignments (Wafers through Steppers) / Total Operators on payroll

Moves/op/shift:
= Number of 'Track-ins' per operator per shift
= Total (lot) Step Moves on a Shift / Total Operators on a Shift

Operators: = Direct Labor = all Manufacturing Non-Exempts (includes Test Wafer associates, reticles group, manufacturing trainers, etc.)

These are the Planning numbers. Typically, unless we're in a ramp-up situation, we find that our average productivity is about 10% below our Planning goal."

Issue 4.02 - A. Najeeb Syed of Agere

"I had a question on one of the topics covered in the last newsletter "Wafer Moves Per Operator". Fab loadings will indeed impact the # of mask aligns, but wouldn't level of automation and type of product running be a bigger impact. For example if in a fab with automated delivery system and more linked tools with automated recipe downloads etc., the operator role will be limited to loading and unloading the lots from the tool. Hence the staffing levels would be low.

Also the comparison can only work between fabs running similar/standard technologies. Products with varying amount of processing per mask level would have a big impact on # of mask aligns per operator, since more operators would be required for technologies with higher amount of processing per mask level. I'll appreciate any feedback."

This concludes our subscriber discussion published to date on operator-related topics. We're sure that there will be more in the future, especially as capacity loading in the industry start (hopefully!) rising. In the next sections, FabTime will summarize a few of our thoughts on Operator Planning and Operator Management.

Operator Modeling/Planning

Many factors influence the appropriate number of operators for a fab, including the size of the fab, lot size, production volume, tool utilization, cycle time targets, and level of automation (a more automated fab will likely need fewer operators than a similarly-sized fab with manual transport). This makes it very difficult to say what is the "right" number of operators, or to compare numbers of operators across different fabs. Our impression is that many fabs do not have any formal staffing models, but rather, numbers of operators are planned using a combination of capacity planning-related spreadsheets, budgetary spreadsheets, and personal negotiation/intuition. Of course, some fabs do have more sophisticated, internally-developed labor models.

There are some commercially available tools that can be used to help estimate the appropriate number of operators for a fab. The Factory Explorer (FX) capacity and

simulation analysis tool can generate headcounts. You specify, for each toolgroup in the model, what percentage of time the operator is required for loading, processing, and unloading wafers. At each process step, you specify the operator group required for processing, and optionally for transport. The FX capacity engine then calculates the required number of operators in each group, based on the product mix. You can enter operator break schedules, and specify how heavily you would want each operator group loaded. This is a very detailed approach, because it relies on having a capacity model that specifies the process times at each step. And you still have to make an assumption about how heavily you want the operator groups to be loaded. However, once you have the detailed capacity model built, you can simulate the same model to estimate cycle time tradeoffs. (For more information see www.wwk.com - Frank Chance was the developer of FX, but it is now owned by Wright Williams & Kelly).

We also know of a number of fabs that incorporate staffing into their Brooks AutoSched AP capacity and simulation models. For more details about this products, see http://www.brooks.com/pages/231_autosched_ap.cfm (or follow links from the main page to Products/Software/Planning and Logistics).

Other commercial labor planning tools are also available. Abbie Gregg, Inc. (FabTime's sales and implementation partner for Arizona and New Mexico) has a labor model called Io. Io is an add-on to AGI's Jupiter Factory Product/Cost Model. Io uses queueing approximations to explore cost/labor/capacity trade-offs. More information is available at AGI's website, www.abbiegregg.com (under Products). Tefen (www.tefen.com) also has a labor planning model, although FabTime is less familiar with this product. Their Staffware product is a queueing based staffing model designed for the semiconductor industry.

Our opinion is that queueing models can be used to capture some of the relative effect of needing to seize an operator resource. However, to look at detailed operator behavior, or to estimate absolute cycle times, it is necessary to use simulation. What we have observed is that if operators are not included in simulation models, the models will tend to consistently underestimate cycle time as compared with actual cycle times in the fab. Even when operators are included, but not modeled in detail, cycle times will be closer to actuals due to the additional level of resource contention when lots wait for both an operator and a tool (especially if breaks are modeled, or the model includes operators being responsible for more than one tool at a time). We believe that if you use your operators for manual transport, this will be especially true (because this is another point at which an operator is needed), and even more so if the operators can batch lots for transport (e.g. there's a cart that can hold six lots at a time).

Operator Management

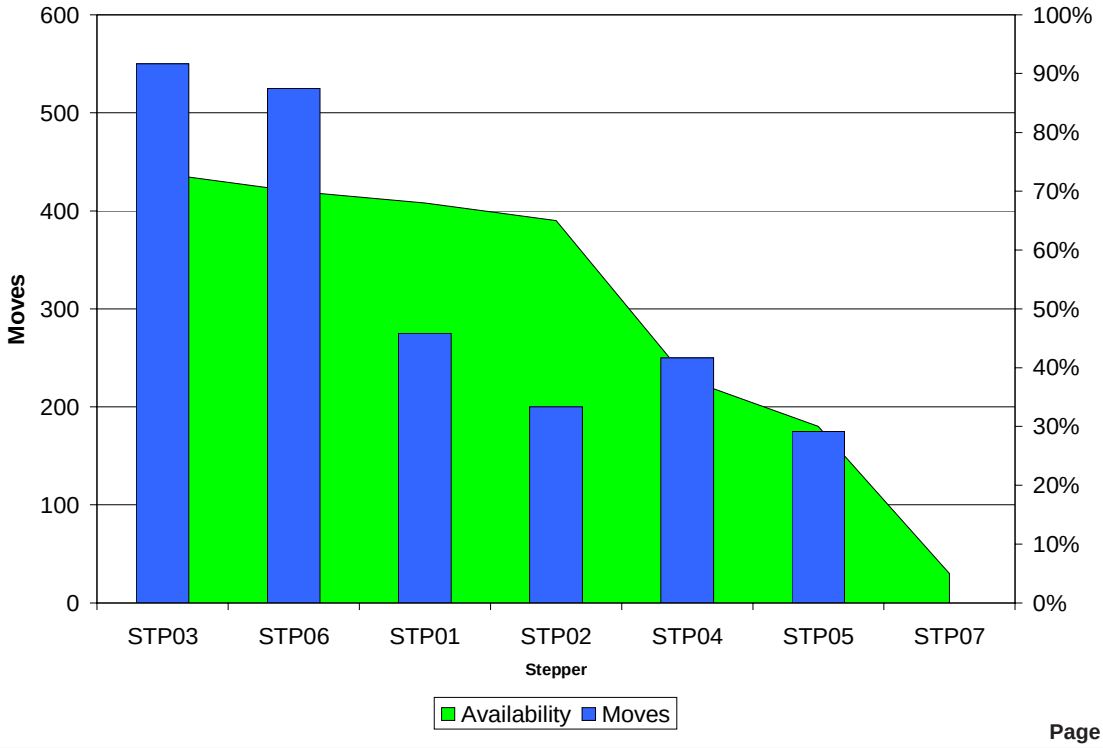
Regarding how fabs measure operator performance, we don't think that there is one simple approach. It's a very complex topic, influenced by the number of tools for which each operator is responsible, and the availability of other resources such as reticles. From a cycle time perspective, we think that what's important is not how busy the operators are per se, but rather, how much time tools spend waiting for operators (at least for bottleneck tools). If your bottleneck tool spends 5% of its time waiting for an operator to load the machine, that unavailable time pushes the tool to a steeper place on the operating curve, and drives up cycle time. If your fab is very cycle time focused, we recommend that you start to measure the time that the

tools spend waiting for operators, and initiate projects to reduce it.

A related point concerns operator preferences for particular tools. In our experience, the largest drivers of cycle time are usually utilization and number of qualified tools. We believe that when comparing to actual cycle times, it's important to look at actual historical move data to identify the set of tools that have been used to do a particular operation. The reason for this (as opposed to just taking the tool qualification matrix) is that operator preferences and/or communication problems can result in fewer tools being used for a particular operation than planned. The resulting utilization on the tools may then be higher than expected. If you are finding that actual cycle times are much higher than expected for an operation, checking the actual set of qualified tools is a good first step. See the chart below for an example - Steppers 01 and 02 had lower moves, despire having nearly the same availablity as Steppers 03 and 06.

The other question that people have raised regularly concerns how much cross-training / cross-qualification of operators is appropriate. Some fabs try to cross-train operators to perform small maintenance tasks, which eliminates long waits for equipment techs, but also increases the load on operators. Other fabs cross-qualify operators as much as possible, so that each operator can be responsible for a large number of tools at one time. Both of these approaches raise the question "how far can you go?" On the one hand, if all of your operators are fully cross-trained, then whenever any tool is in need of an operator, the likelihood is very high that an appropriate operator will be available. However, this raises logistical issues, because the operators need to know which tools to monitor. You can easily simulate having one large pool of operators, but in practice, you need to assign the operators to areas.

We believe that the amount of cross-training to use depends on the size of your factory, and on how much slack capacity the operators have. If your operators end up very highly loaded due to additional activities, then you'll end up with cycle time delays due to tools being ready for



processing when no operator was available. The idea behind ordinary cross-training of operators to be able to use multiple tools is much like the idea of reducing tool dedication, and should improve cycle times in the same way as long as logistical issues regarding which tools to manage don't become a problem. However, if you include training for other types of activities, to the point where the operators are sometimes not available when the tools need them to be, then you can hurt cycle time. For cycle time, the idea is to maximize the amount of time that operators are available to process lots at tools, and to transport lots, so that lots are never delayed because of operator unavailability.

Conclusions

Planning for the "right" number of operators in a fab and then managing cross-qualification and evaluating operator performance are complex issues. Operator-related questions and comments are by far the most frequent submissions that we've received for our subscriber discussion forum over the past year. There are a few commercial tools available to help investigate trade-offs, and there have been a number of papers published on operator-related topics (see below). However, our impression is that the subscriber community would like to see better models and more comprehensive benchmarking in the area of operators. In light of this, we're working to add more operator-specific reporting to our FabTime cycle time management software, and to better account for operator delays in our queueing-based operating curve generator.

Closing Questions for FabTime Subscribers

What do you think about the topics discussed in this newsletter issue? FabTime is a software company. We don't manage operators ourselves. But we can act as a collection point for information related to operator planning and operator management, preserving confidentiality where necessary. If you have papers on this topic, or publicly available models/spreadsheet tools, or just informal thoughts and experiences which you are willing to share with the newsletter community, we would love to hear about them. Thanks!

Further Reading on Operators

Unless otherwise stated, these articles are not available from FabTime. You can purchase many of them from Infotrieve (www.infotrieve.com), a third-party article tracking service.

- G. M. Campbell, "Cross-Utilization of Workers Whose Capabilities Differ," *Management Science*, Vol. 45, No. 5, 722-732, 1999. This paper is not semiconductor-specific, but it does look at the preferred amount of cross-utilization as a function of variability.

- F. Chance and J. Robinson, "The Impact of Staffing on Cycle Time," *FabTime Cycle Time Management Newsletter*, Vol. 3, No. 9, 2002. This issue is available for purchase from FabTime's Amazon zShop (http://www.Amazon.com/shops/FabTime), for $9.95.

- 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.

- W. Chou and J. Everton, "Capacity Planning For Development Wafer Fab Expansion," *Proceedings of the 1996 IEEE/SEMI Advanced Semiconductor Manufacturing*

Conference, Cambridge, MA, 17-22, 1996.

■ J. K. Cochran, D. E. Chu and M. D. Chu, "Optimal Staffing for Cyclically Scheduled Processes," *International Journal of Production Research*, Vol. 35, No. 12, 3393-3403, 1997. This paper includes a case study from semiconductor manufacturing.

■ T. Croft, S. Sheamer, and T. Baker, "Wafer Fab Labor Modeling with Queueing Theory," *Proceedings of the 2002 International Symposium on Semiconductor Manufacturing (ISSM2002)*, Tokyo, Japan, 2002.

■ 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. A PDF of this paper can be requested from Jennifer.Robinson@FabTime.com.

■ Y.-F. Hung and I.-H. Chen, "Dynamic Operator Assignment Based on Shifting Machine Loading," *International Journal of Production Research*, Vol. 38, No. 14, 3403-3420, 2000. This study proposes a way to improve the efficiency of semiconductor wafer fabrications by better allocating operator resources.

■ Y. Ishii, "Workload Analysis and Productivity Improvement Using Video Footage," *Proceedings of the 2002 International Symposium on Semiconductor Manufacturing (ISSM2002)*, Tokyo, Japan, 2002.

■ 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. 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.

■ E. Molleman and J. Slomp, "Functional Flexibility And Team Performance," *International Journal of Production Research*, Vol. 37, No. 8, 1837-1858, 1999.

■ S. A. Mosley, T. Teyner, and R. M. Uzsoy, "Maintenance Scheduling And Staffing Policies In A Wafer Fabrication Facility," *IEEE Transactions on Semiconductor Manufacturing*, Vol. 11, No. 2, 316-323, 1998.

■ D. S. O'Ferrell, "Manufacturing Modeling and Optimization," *Proceedings of the 1995 IEEE/SEMI Advanced Semiconductor Manufacturing Conference*, Cambridge, MA, 334-339, 1995.

■ A. Raviv, "Applications of Queuing Theory and Simulation to Staffing in the Semiconductor Clean Room Environment," *Proceedings of the 1995 IEEE/UCS/SEMI International Symposium on Semiconductor Manufacturing*, Austin, TX, 252-256, 1995.

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