FabTime Cycle Time Management Newsletter

Volume 4, No. 8 August 2003

Information

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

Publisher: FabTime Inc. FabTime sells cycle time management software for wafer fab managers. We are currently installing Version 5.5 of FabTime. New features include an Employee filter for moves, turns, operation cycle time, and WIP charts, and a new Tool State Transaction List chart for analysis of individual equipment events.

Contributors: Brian Denton (IBM)

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Welcome

Welcome to Volume 4, Number 8 of the FabTime Cycle Time Management Newsletter. We have no subscriber discussion this month (summer vacation, perhaps?), but we do have a couple of announcements. I will be in Boise next month, giving at talk at the APICS Treasure Valley Chapter. I hope to see some of you there! We also have an announcement from Brian Denton about a special session at the next INFORMS Conference on applications of Operations Research to semiconductor manufacturing. Several abstracts are included, and a number of subscribers to this newsletter are represented.

In an effort to make this newsletter more useful to customers of our FabTime cycle time management software, we are adding a new section: the FabTime User Tip of the Month. This very brief section will highlight new features or suggested usages of existing features that our customers may find helpful.

This month's main article is about the performance metric Dynamic X-Factor. We read about this metric in an ISSM 2002 paper by researchers at Yasu Semiconductor in Japan, and we think that it is very useful. Dynamic X-Factor measures the speed of the production line, on a short-term basis, and gives an early indicator of when cycle time problems are building. As proposed in the Yasu paper, Dynamic X-Factor is easy to calculate, and can be shown to be equivalent to the traditional cycle time X-Factor on a long-term basis.

Thanks for reading!—Jennifer

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Community News/Announcements

FabTime Cycle Time Management Presentation at Treasure Valley APICS Meeting

FabTime's Jennifer Robinson will be giving a Keynote Presentation on Current Issues in Cycle Time Management at the September 23rd meeting of the APICS Treasure Valley Chapter in Boise, Idaho. Topics discussed will include benefits and challenges of cycle time management, the relationship between cycle time and utilization, cycle time impact of downtime and variability, and top cycle time issues today in manufacturing. The meeting will be at 6 pm, in the Boise State University Student Union Building. The cost to attend (including the presentation and dinner) is $15 for students, $20 for APICS and NAPM members, and $25 for non-members. RSVP by September 10th to j_bsmith@msn.com. Attendance is limited to the first 75 registrants.

If you can't attend the meeting, but would like to meet to meet with Jennifer on the afternoon of September 23rd or the morning of the 24th to see a demo of FabTime's web-based cycle time management software, just email Jennifer.Robinson@FabTime.com to make arrangements.

INFORMS Session on Applications of Operations Research to Semiconductor Manufacturing

The following session, scheduled at the 2003 INFORMS Annual Meeting in Atlanta Oct. 19-22, features several talks on applications of operations research and management science to the semiconductor manufacturing industry. The goal of the session is to present industry applications to a variety of interesting problem areas and motivate future applications and research. Those attending the session will find the talks cover a range of topics from detailed scheduling of wafer fabs to long range strategic planning of enterprise resources.

Session Title: "Applications of OR to Semiconductor Manufacturing" Session Chair: Brian Denton, IBM - 958C, 1000 River Street, Essex Junction, VT 05452, bdenton@us.ibm.com

Talk 1 Title: "Impact of Factory Operations Research (FORCe) on Semiconductor manufacturing" Authors: Mani Janakiram, Intel Corporation; Frank Robertson, SRC/Intel; K.J. Stanley, ISMT/ Motorola; John Fowler, Arizona State University

Abstract: Factory Operations Research Center (FORCe) a 3 year, ~ $1million/ year, effort between SRC and ISMT, addresses the ITRS factory operations challenges. These 5 projects address demand planning, PM, scheduling and modeling. University researchers are working together with MC's to develop solutions. The last year of the FORCe is focused around providing pathways for commercialization and implementation of the research results and that would be discussed at detail in this presentation.

Talk 2 Title: "On Experiences Using The Operating Curve Methodology for Controlling and Performance Evaluation of Semiconductor Manufacturing" Authors: Alexander K. Schoemig; Manfred Mittler, Infineon Technologies AG

Abstract: In 1997 Infineon Technologies started the Productivity Offensive. The Operating Curve Methodology was introduced as the standard factory productivity measurement along with new performance indicators. We discuss the experiences concerning the application of this methodology and elaborate about shortcomings of the operating curve methodology and present directions for future research.

Talk 3 Title: "Supply Chain Optimization in the On-Demand Era" Authors: Robert Orzell, IBM

Abstract: OR methods have been used extensively in production planning in IBM's Microelectronics Division. We describe the evolution of such techniques over time to cover an increasing number of essential business processes. We also describe the evolution of using such techniques to support on-demand operating environments and further goals and challenges in this arena.

Talk 4 Title: "A Semiconductor Manufacturing Model with Multiple Grade Products and Downgrading" Authors: Guillermo Gallego, Kaan Katircioglu, Bala Ramachandran, IBM

Abstract: We present a multi-echelon inventory model of a semiconductor manufacturing process that enables the analysis of drivers of supply chain performance. The model includes consideration of the multiple grades of products produced by the manufacturing process and effects of downgrading inventory.

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

FabTime User Tip of the Month

Use Quick-Jump to Navigate Between Charts

In an effort to make this newsletter more useful to customers of our FabTime cycle time management software, we are adding a new section: the FabTime User Tip of the Month. This very brief section will highlight new features, or suggested usages, that our customers may find helpful.

"Quick Jump" navigation has been part of FabTime since Version 4.0. Most of the charts in the software belong to a quick jump set of related charts, so that you can quickly switch between charts in the same set. For example, the Moves Trend chart is in a Quick Jump set with several other charts, including the Tool State Trend chart, the Operation Cycle Time Trend chart, and the WIP Trend chart. Suppose that you are looking at the Moves Trend chart for a particular area, and notice that the moves decreased during one shift. You can use the Quick Jump set to jump over to the Tool State Chart for the same area, to see if the decrease in moves was due to an availability problem. Similarly, you can jump to the WIP Trend chart, to see if the problem was due to lack of WIP. Any filters and time periods that you have set on the first chart will "stick" when you quick jump.

The Quick Jump control is located just above the data table on all chart pages (provided the chart is part of a quick jump set). To use the Quick Jump control, simply select your destination chart from the drop-down list labeled "Quick Jump to:", and then press the "Go" button below. To return to the previous chart, you can either use your browser's "Back" button, or use the Quick Jump control again.

We find that even experienced FabTime users sometimes forget about this convenient feature, and we are highlighting it here to make sure that our users know about it. If you have any questions about this feature (or any other software-related issues), just use the Feedback form in the software.

Subscriber Discussion Forum

This section is dedicated to subscriber discussion, including responses to previous newsletter articles, and other questions or topics raised by subscribers. This month, for the first time in more than 2 years, we do not have any subscriber discussion. If you have a question related to wafer fab cycle time, or a response to anything discussed in recent issues of the newsletter, we encourage you to send it to Jennifer.Robinson@FabTime.com for inclusion in the next issue.

Dynamic X-Factor

Introduction

As a company focused on wafer fab cycle time management, FabTime has long been interested in early indicators of cycle time performance. Friends in Japan recently brought to our attention a metric called Dynamic X-Factor. This metric was proposed at the 2002 ISSM conference in Japan by researchers from Yasu Semiconductor (S. Johnishi, K. Ozawa and N. Satoh - the full reference is below). Dynamic X-Factor is a point estimate of production line speed, used to quickly identify deviation from cycle time goals.

At FabTime, we use the traditional cycle time X-Factor quite a bit for understanding fab behavior. Here X-Factor = Actual Cycle Time / Theoretical Cycle Time. Theoretical Cycle Time typically refers to the sum of load, unload, and process times for any lot, but does not include queue time or transport time. Theoretical Cycle Time is also sometimes called Raw Process Time (RPT). Actual cycle time, of course, is the time from when a lot is started into the fab until it ships. X-Factor can be calculated by process, or taken as a weighted average across all of the processes shipping from the fab.

There are a number of papers that refer to this definition of X-Factor – the earliest appear to be those by Don Martin of IBM. X-Factor is also discussed in the 1987 book "World Class Manufacturing Case-book", by Richard Schonberger (see full reference below). In the first section of this book, Schonberger discusses "Ratio analysis" using three ratios, one of which is "lead time to work content" (X-Factor), and another of which is "number of pieces to number of workstations" (which turns out to be much like Dynamic X-Factor). By graphing X-Factor vs. utilization to generate the fab's operating curve, we can explore cycle time vs. utilization tradeoffs under different conditions (e.g. amount of variability, number of tools, etc.). Our FabTime cycle time management training class uses operating curves and X-Factors extensively to build intuition about fab behavior. You can also experiment with operating curves yourself using our free operating curve generator spreadsheet tool (www.fabtime.com/charcurve.shtml).

The trouble with the overall cycle time X-Factor (shipped lot cycle time / theoretical process time) is that it is a trailing metric. It tells how the fab did over the past several weeks, but lags as an indicator of current performance. X-Factor also can be difficult to calculate, because it relies on knowing the theoretical cycle time for every operation. And there is a question of what horizon to use for the calculations. All the lots that shipped today? In the past week? Etc..

One way to get around the problem of X-Factor as a trailing metric is to look at operation-level X-Factors. Here we record actual cycle times for the lots that complete an operation and divide the average by the theoretical process time for the operation. Operation-level X-Factors give an indication of which operations are having cycle time problems, on a more short-term basis. However, they are not as useful as a general guide regarding how the fab is doing. For example, we might habitually run a bottleneck operation at 6X, and have that built in as part of the planned overall cycle time (because other non-bottleneck operations are much faster). So, we would still like a metric that's directly related to cycle time, gives one number as an indicator for the fab, does not require collection of too much theoretical data, and is forward-looking. Dynamic X-Factor meets these requirements.

Dynamic X-Factor Definition

Dynamic X-Factor is a point estimate. It is calculated solely on the basis of WIP in the line, and whether or not the WIP is currently being processed. Specifically, we have:

Dynamic X-Factor = Total Number of Wafers / Total Number of Wafers in Process

Here the total number of wafers includes production lots and engineering lots. Number of wafers in process includes all WIP currently being worked on at a tool. (Note: this leaves us with the slightly awkward term WIP in process, where WIP is work in progress. When we say WIP we mean any wafers that have been started into the fab, and we reserve WIP in process for wafers currently being worked on). Dynamic X-Factor can be calculated fairly easily from the Manufacturing Execution System (MES), at any given point in time. No lot history or theoretical process time data is required - just the current status of the WIP at that point.

Although not addressed in the Johnishi paper as part of this definition, we think that the denominator should really be "non-rework wafers in process", rather than including all wafers in process. The reason, of course, is that rework inflates cycle time, without being included in theoretical cycle time. In the discussion that follows, where we refer to wafers being processed, you can assume that we have clarified this definition to mean non-rework wafers.

We think that this is a nice metric. It can be broken down by process flow, or by area or tool-group, and generated at regular intervals to form a control chart. While the point values will fluctuate some (especially for individual tools), they should tend to center around some average value. In the long-term, this average value can be shown to be equal to the cycle time X-Factor described above (see details below). In the shorter-term, however, the Dynamic X-Factor gives a single number that is an early indicator of cycle time problems.

If Dynamic X-Factor is increasing, this means that a smaller proportion of WIP is being worked on - either because the amount of WIP is increasing, or because the WIP in the fab is sitting. By contrast, if Dynamic X-Factor is low, it means that much of the WIP that is in the fab is currently being processed. And of course the more time WIP spends being processed (as opposed to sitting in queue) the shorter our cycle times will be.

Dynamic X-Factor can also be calculated separately for hot lots (total number of hot lots / number of hot lots in process). This should give a lower Dynamic X-Factor, an indication of the relative velocity of hot lots in the fab. For super-hot lots (hand-carry lots), any lots in the fab should almost always be in process, so the Dynamic X-Factor should be very close to one over time.

Limitations

Care must be taken in reporting Dynamic X-Factor, because if infrequently updated (e.g. once a day), there could be a short-term incentive for operators to leave completed lots sitting at tools, instead of moving them out. This would tend to artificially reduce the Dynamic X-Factor, but is obviously not good in terms of cycle time. We recommend that if you use Dynamic X-Factor, you generate values frequently, to remove this incentive. If you do only generate values once a day, we suggest that they not be taken right at shift change, when there might be fewer lots in process than at other times.

Also, although somewhat scalable down to individual areas and tool groups, the denominator of this metric is number of wafers in process. This means that Dynamic X-Factor will go to infinity when there are no wafers in process (e.g. because a tool is down or idle). One possible to solution to this problem would be to substitute a one into the denominator for cases where there are no (non-rework) wafers in process. In this case, Dynamic X-Factor would revert to the amount of WIP waiting for the tool, or tools. You could then flag cases with a non-zero Dynamic X-Factor where the tool is not currently processing (this tool has WIP, why isn't it being worked on?).

Dynamic X-Factor also needs to be adjusted carefully if the entire fab is shut down for any reason. Johnishi et. al. describe how to do this in their paper.

The Relationship Between Dynamic X-Factor and Cycle Time X-Factor

In this section, we show mathematically what already makes sense intuitively: that in the long term, Dynamic X-Factor will work out to be equal to the traditional cycle time X-Factor. Dynamic X-Factor says: of the WIP we have in the line, how much are we working on at any given point, and how much do we have sitting?

Say the Dynamic X-Factor works out to be four, for example. This means that for every lot in process in the fab, there are three lots in queue (or in transit to the queue). Every time a lot gets processed, it first has to wait in queue (on average) for those three other lots to be processed. So, we would expect that its average cycle time by operation would be about four times the average process time (consisting of three intervals of queue time while other lots are processed, plus one interval of actual process time).

More formally (though note that this is a justification, not a formal proof), let

- W_{tot} = Total cycle time (average)
- TPT_{tot} = Total process time (average)
- L_{tot} = Total WIP in the fab
- $Lambda_{Start}$ = Arrival rate into the fab
- TPT_{avg} = Average process time for a single step
- N_{Steps} = Number of steps
- L_{proc} = Total WIP currently being processed
- $Lambda_{Proc}$ = Total arrival rate to all individual steps (summed across all steps)

We want to estimate X-Factor = cycle time / theoretical process time

- X-Factor = W_{tot} / TPT_{tot} (1)

We know that total cycle time = total WIP / total system arrival rate (from Little's Law) and so we have:

- $W_{tot} = L_{tot}/Lambda_{Start}$ (2)

Now, the total process time is the sum of the process times for the individual steps, and we have:

- $TPT_{tot} = TPT_{avg} * N_{Steps}$ (3)

The average process time for a step is equal to the wafers in process at the step divided by the arrival rate to the step. This is also from Little's Law (it applies to the whole system, or the queue, or the process time). And we have:

- $TPT_{avg} = L_{proc} / Lambda_{Proc}$ (4)

So, substituting equation (2) and equation (3) into equation (1), our estimate for cycle time X-Factor is:

- X-Factor = $W_{tot} / TPT_{tot} = (L_{tot}/Lambda_{Start}) / (TPT_{avg} * N_{Steps})$

Substituting in equation (4) for TPTavg, we have:

$= (L_{tot}/Lambda_{Start}) / ((L_{proc} / Lambda_{Proc}) * N_{Steps})$

Rearranging terms (inverting and bringing up the denominator), we get:

$= (L_{tot} / L_{proc}) * (Lambda_{Proc}) / (Lambda_{Start} * N_{Steps})$

Now, the total arrival rate to the process steps is equal to the arrival rate into the system multiplied by the number of steps, and so we have:

- $Lambda_{Proc} = Lambda_{Start} * N_{Steps}$

This means that the right-hand factor above goes to 1, leaving

- X-Factor = (L_{tot} / L_{proc}),

which is total WIP divided by WIP in process. This is the definition of Dynamic X-Factor.

Summary

Dynamic X-Factor measures, on a point-in-time basis, how much of the WIP in the line is currently being worked on, instead of sitting in queue. If Dynamic X-Factor drifts upward, cycle time will probably start to increase in the future (because either there is more WIP, or WIP in the line is sitting more than it should be). Dynamic X-Factor is calculated by taking the total number of wafers in the fab and dividing by the number of non-rework wafers actually being processed. While Dynamic X-Factor works out to be the same as the regular cycle time X-Factor (cycle time / theoretical cycle time) on a long-term basis, Dynamic X-Factor is easier to calculate, and is more forward-looking than an X-Factor based on shipped lot cycle times. While there are some limitations to this metric, we think that it provides a useful indicator of current fab cycle time performance. We recommend its use.

Closing Questions for FabTime Subscribers

What do you think about this metric? Does your fab use X-Factors? Are they measured on a dynamic basis, or on more of a historical basis for completed lots? If you do use a Dynamic X-Factor, do you calculate it based on total wafers vs. wafers being processed? Or do you calculate Dynamic X-Factor based on cycle time vs. theoretical cycle time? Have you been able to use this metric to drive cycle time improvements? Are there other limitations that we're missing here? Send your responses to any of these questions to Jennifer.Robinson@FabTime.com, and we will include them in the subscriber discussion forum of the next issue.

Further Reading

- D. Delp, J. Si, Y. Hwang, B. Pei, "A Dynamic System Regulation Measure for Increasing Effective Capacity: the X-Factor Theory," *Proceedings of the 14th Annual IEEE/SEMI Advanced Semiconductor Manufacturing Conference and Workshop*, Munich, Germany, 2003.

- S. Johnishi, K. Ozawa and N. Satoh, "Dynamic X-Factor Application for Optimizing Lot Control for Agile Manufacturing," *Proceedings of the 2002 International Symposium on Semiconductor Manufacturing (ISSM2002)*, Tokyo, Japan, 2002.

- M. Kishimoto, K. Ozawa, K. Watanabe, and D. Martin, "Optimized Operations by Extended X-Factor Theory Including Unit Hours Concept," *IEEE Transactions on Semiconductor Manufacturing*, Vol. 14, No. 3, 187-195, 2001.

- D. P. Martin, "The Advantages of Using Short Cycle Time Manufacturing (SCM) Instead of Continuous Flow Manufacturing (CFM)," *Future Fab International*, Volume 9, 1999.

- D. Martin, "How the Law of Unanticipated Consequences Can Nillify the Theory of Constraints: The Case for Balanced Capacity in a Semiconductor Manufacturing Line," published in *Semiconductor FabTech*, see www.fabtech.org/journals/edition.07/section1.shtml, May 1997.

Subscriber List

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TriQuint Semiconductor (9)
Tru-Si Technologies (1)
TRW (4)
TSMC (18)
TVS Motor Company (1)
UMC (7)
United Monolithic Semiconductors (2)
Unitopia Taiwan Corporation (1)
University College of Cape Breton (1)
University of Aizu - Japan (1)
University of Arkansas (1)
University of California - Berkeley (6)
University of Cincinnati (1)
University of Groningen - Netherlands (1)
University of Illinois (2)
University of Karlsruhe (1)
University of Notre Dame (1)
University of South Florida (1)
University of Southern California (2)
University of Texas at Austin (2)
University of Ulsan - S. Korea (1)
University of Virginia (2)
University of Wuerzburg - Germany (1)
Univ. Muhammadiyah Surakarta (1)

University Porto (1)
VIR, Incorporated (1)
Virginia Tech (7)
Vishay (1)
Voltas Limited (1)
Vuteq Corporation (1)
Wacker Siltronic (2)
WaferTech (17)
Win Semiconductor (1)
Winbond Electronics Corporation (1)
Wright Williams & Kelly (5)
Xerox Brazil (1)
X-FAB Texas, Inc. (3)
Yonsei University (1)
Zarlink Semiconductor (2)
Zetek PLC (1)
ZMC International Pte Ltd (2)
Unlisted Companies (24)

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