FabTime Cycle Time Management Newsletter

Volume 4, No. 5 May 2003

Information

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

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Welcome

Welcome to Volume 4, Number 5 of the FabTime Cycle Time Management Newsletter, and Happy Spring! Subscriber discussion topics for this month include three responses to last month's article about cycle time and equipment downtime; a response to last month's subscriber discussion topic of cycle time and integrated metrology; and a response to last month's subscriber discussion question about automated material handling and cycle time goals.

This month's main article is about arrival variability and cycle time. While working with our FabTime cycle time entitlement calculator (described in Volume 4, Number 3), we observed some interesting behavior for cases with a high degree of arrival variability. We found that arrival variability due to batching tends to have less of an impact on cycle time than other types of arrival variability. In this article, we show examples generated from simulation models, and discuss the impact of this behavior on the formulas in our operating curve generator and entitlement calculator. We also introduce a modification to our operating curve generator that accounts for arrival batching.

Thanks for reading!—Jennifer

FabTime

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Community News/Announcements

OpVent Conference and Exhibition

We received the following announcement about the OpVent Conference, to be held later this month in Germany:

May 22nd - 24th, 2003
OpVent Conference and Exhibition
"International Conference on Business Opportunities and Joint Ventures"
IZET Innovationszentrum Itzehoe
Fraunhoferstr. 3
25524 Itzehoe, Germany

OpVent 2003 offers exciting opportunities for high-tech companies and their entrepreneurial visions. They will get the chance to meet international experts, financiers and potential partners and to expand their networks. OpVent 2003 can be used as a platform e.g. to meet with existing German contacts.

Our programme includes:

- International business meeting "Community-Treff"
- Lectures on the topics of markets in the metropolitan area of Hamburg, company establishment & expansion and financing
- Sport events: Golf tournament - Innovation Cup of Itzehoe - or a sailing trip on the Elbe River

For more details see www.opvent.com.

PDF Newsletter Subscription Option

We have had several people write to tell us that they find the text version of this newsletter difficult to read. If you find the text email version hard to read, or you like to save the past newsletter issues, you may wish to consider changing to the formatted PDF version. The PDF version is sent as an attachment, and is usually about 200 KB in size. The PDF version contains all of the content from the text email version, and sometimes also includes graphs and pictures (which cannot be easily included in the text version).

If you would like to switch to the PDF version, or would like to receive both the text email and the PDF versions, just reply to the newsletter message and let us know. Alternatively, you can re-submit the subscription form, at www.FabTime.com/newsletter.shtml, indicating your preference for newsletter format. There is no charge to subscribers to receive the current newsletter in PDF format. We do charge for past issues of the newsletter. These are available from our Amazon zShop at www.amazon.com/shops/fabtime for $9.95/issue.

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

Subscriber Discussion Forum

Cycle Time and Equipment Downtime

Arnie Stein (Hynix) wrote in response to last month's main article. "I can't help but comment on the number one contributor to cycle time, downtime. It's very much a double-edged sword. 1) Preventative maintenance, if done correctly, will reduce unscheduled downtime. 2) You can't PM everything, so PM the issues that cause unscheduled downtime. 3) Where do you want to suffer the cycle time loss? During a planned event, where you have control over the plan, or, during an unscheduled downtime event that will cost you more in time, money and manpower? It's been my experience that unscheduled downtime is easier to get money for repairs than scheduled PM work. Scheduled PM work needs to be budgeted. Budgets need to get approved. What a better way to cut costs by cutting the budget for scheduled PM work. The result, higher unscheduled downtime, longer cycle times, possible scrap, more manpower, etc. You should see what unscheduled downtime will do to headcount models!"

V.A. Ames (Productivity System innovations) also wrote in response to last month's article. "The last newsletter concerning the effect of equipment variation on factory cycle-time is one of FabTime's best. The points that you raised should be of great interest to everyone and the use of the operating curve generator was very effective. Since reducing the effect of equipment variation on factory cycle-time is my primary focus, I want to share a few my thoughts on the subject.

I believe that variations in factory cycle-time can be broken down into three main factors:

1) Wafer management - which includes, line design, WIP management, tracking wafers through the line, managing hot lots and engineering wafers, and Lean Manufacturing methodologies.
2) Process robustness and stability.
3) Equipment variation.

Equipment variation has become the number one issue because factories have spent a lot of resources on IT solutions and software, like FabTime's, to address wafer management issues and obviously an enormous amount of effort is continuously placed on creating processes that are under control.

If we look at equipment, however, very little has changed regarding equipment support methods since preventive maintenance was introduced in the 1950's! We have designed equipment around processes, automated some equipment activities, and created a host of metrics to measure performance, but have not effectively changed the way maintenance is performed or how equipment can be designed for optimum maintainability. The current interest in e-Diagnostics is the first effort to monitor equipment conditions on an ongoing, insitu, basis. There are some issues with implementing e-diagnostics, however, like justifying the cost and knowing what to monitor.

There are proven methods that can be implemented more easily, and cheaply, to improve equipment reliability, availability, and maintainability. My interest is to help factories use their current resources to identify what needs to be monitored on their critical equipment sets and establish the basic equipment conditions. These conditions are then easily monitored on a regularly basis by the operator to identify any changes in performance so potential failures can be detected before the process is interrupted or quality is compromised.

If any of your subscribers are interested in leaning more about equipment focused TPM they can contact me directly at vames@productivitysi.com."

Vincent Corbett of Analog Devices submitted a question about cycle time and equipment downtime. "I am trying to develop a very simple EXCEL table that can model the effect of down-time on the CT for a given tool/tool set. The FabTime operating curve generator is a degree too complex for what I need. I am trying to model the effect of losing 1 tool in an equipment set and also model the impact of long MTTR on CT. I'm thinking of something like this:

Tool set A
:# tools:

:# Lots:Proc time:Down-time:Recov. time:

Daily arr: (mins) : (days) : (days) :
(based on loading)

'effect' on CT over recovery period? = ___

Any help from other newsletter subscribers would be appreciated." FabTime does not currently have an Excel tool like this. If any other subscribers know of any non-proprietary tools that might address Vincent's questions, please let use know, and we will pass the word along to Vincent.

Cycle Time and Automated Material Handling (AMHS)

David MacNicol of the National Microelectronics Institute in the United Kingdom wrote in response to last month's subscriber discussion topic on AMHS and cycle time. "Cycle time is essentially a combination of two factors - process time (or theoretical time) and queue time. Most fabs (certainly in the UK and many European fabs) perform at a factor of around 3.5 - 5 x of this theoretical time. Based on straightforward pareto analysis, the greatest potential for cycle time reduction lies in the queue time - not processing times.

We know that queue time consists of many sub-categories, including the usual operator and equipment availability, transportation time, process holds and the impact of single batch to multi-batch loading (waiting to fully load furnaces etc). As an aside here, I noted in the previous newsletter that STMicroelectronics had indicated the difficulty in measuring manual transportation times. We actually measured these fairly accurately and in some cases it helped us justify relocating or buying additional metrology tools. I also know of one fab in Fareast Asia that removed its AMHS because material could be transported more quickly manually. Essentially, transportation times was not a great factor for us in cycle time.

Our fabs are not balanced in terms of throughput capability and Goldratt claimed we should not aim to do this - equipment costs would make it prohibitive in any case. Most fabs (at least the older fabs) continue to use the traditional "push" mentality and this means that WIP inevitably ends up queuing - in fact we end up with a number of queues, which mutate into WIP mountains that grind their way through the line, accruing large amounts of cycle time as they go.

Our analysis of many fabs indicates that on average they can have up to 50% of their WIP idle at any given time. Further analysis has shown that most of this WIP is actually queuing behind other WIP. A solution therefore would seem to be relatively simple - have less WIP queuing. How though can this be done? This is the bit where we start to hear terrifying terms like "kanban" or "JIT", but we can rename them so that they are more user-friendly;

so we end up with terms like "rules-based dispatch" or "demand-based expedition".

Whatever you call it, we get better linearity and less queuing by using the pull system that Toyota blessed us with. It works for other sectors but we seem reluctant to overtly use it. We used it at a plant in Scotland and we ran at 1.25 days per mask layer (2.2.x theoretical), with an OTD of 99%. Linearity in a production line is ironically difficult for the semiconductor industry to achieve, but it is possible if we emulate what works well in other sectors."

Cycle Time and Integrated Metrology

Henk Niesing of ASML wrote in response to last month's subscriber discussion topic on cycle time and integrated metrology: "Within our company there are projects ongoing to obtain a better understanding of the factors in the litho area affecting/improving cycle time and variability. The objectives are to work together with our customers on solutions in the Litho area to reduce cycle time and variability. In my view, equipment suppliers for the lithography area have thus far successfully focused their lithography solutions towards overlay, imaging and throughput improvements. For some time now ASML has been expanding it's view of lithography to also include cycle time and variability. This opens up a whole new area of opportunity for us to help our customers meet their business goals. Your FabTime Newsletter and the additional information sources that you highlight certainly give us good directions in which to focus."

Arrival Variability and Cycle Time

Introduction

In Volume 4, Number 3 of this newsletter, we defined cycle time entitlement (the best achievable cycle time given short-term realities like downtime characteristics, staffing, and utilization). As we have discussed many times in this newsletter, one of the primary drivers of cycle time entitlement is variability, both in times between arrivals and in process times. In Volume 4, Number 1 we described the metric coefficient of variation, which quantifies the impact of variability, and is one of the inputs in estimating cycle time. Coefficient of variation (CV) is calculated for a series of values by taking the standard deviation of the values and then dividing by the mean. This gives a dimensionless metric that indicates how variable the data is.

A coefficient of variation of 1.0 corresponds to a system with "moderate" variability. More generally, the text Factory Physics defines moderate variability data to be that with $0.75 < CV <= 1.33$, with any higher CVs corresponding to high variability systems. When you use queueing models to approximate the behavior of fabs, a typical simplifying assumption is to assume that arrivals have moderate variability, and that process times have low to moderate variability. This assumption works well, in that more of the queueing formulas apply exactly when CV=1.

However, as we've been promoting the idea of measuring arrival CVs, and talking with people who do measure them, we've found that actual arrival CVs in fabs tend to be solidly in the high variability range. Values of 2, or 3, or even 4 are not uncommon. Some of this variability is due to batching (both batch processing upstream and batch transfer between steps), though equipment downtime undoubtedly also plays a significant role.

When we started putting these high values for arrival CV into our cycle time entitlement calculations, we found that they drove up the cycle time estimates quite a lot. This is because the formulas include a term that looks like (CVa^2 + CVs^2)/2, where CVa is the coefficient of variation of the times between arrivals, and CVs is the coefficient of variation of process times. Since the CV values are squared in the formula, whenever they are larger than one the cycle time estimates will increase rapidly.

We decided to use simulation to get a sense for whether actual cycle times would really increase as much as predicted by the queueing formulas for cases with arrival CV greater than 1. We found that the answer depended, in part, on the source of the arrival variability. When we had pure batch arrivals (e.g. batches of 3 lots arrive every so many minutes), the simulated cycle times were not as high as the predicted cycle times. However, for non-batch, high variability arrivals, the simulated cycle times were somewhat higher than the predicted cycle times. Batch arrivals breaks a queueing formula assumption, so we need to modify our queueing formulas to address this issue. Details follow.

Simulated Results vs. Analytic Results

We first did a series of simulation experiments where the CV of arrivals was high due to batch lot releases. We simulated a single tool, for approximately 20,000 arrivals, and 3 replications each. We did experiments at five different utilization values (50%-90%) and five CV values, where the CV values were determined through the lot release size. Specifically, we did runs with lots released in batches of 2, 3, 4, 8, and 12 (one fixed arrival batch size for each run). These batch sizes corresponded to arrival CVs of 1.73, 2.24, 2.64, 3.88, and 4.81, respectively.

We then did another set of simulation experiments with the same overall arrival CVs, but with the variability achieved through non-batch lot releases. (We used a hyperexponential-3 distribution, which lets you do things like have most of the interarrival times be small, but then have a few large ones thrown in). We then compared the two simulated results with the predicted results from our entitlement calculator.

Our results showed that when the arrival variability was due to batching, the resulting cycle times were not as high as when the arrival variability was just inherent in the system (not due to arrival batching). The results also showed that the queueing theory results from our Entitlement Calculator tended to over-estimate cycle time when the arrival variability was due to batching, especially at higher utilizations. When the arrival variability was not due to batching, the queueing theory estimates tended to be slightly lower than the simulated cycle times, except at the highest utilization values (which could be due to an initialization issue in these high cycle time simulations).

Here are the results for the highest CV value (CV = 4.81, corresponding to arriving batches with 12 lots). Numbers shown in the last three columns are cycle time x-factors (average cycle time / raw process time). The last column is the Entitlement Calculator queueing theory results. The results for the other CVs were similar, though not as pronounced.

CV=4.81 [Arriving Batches w/12 lots]

Util.	Batch	Non-Batch	QT
50%	12.81	17.80	13.07
60%	16.00	24.78	19.10
70%	21.40	34.81	29.16
80%	33.67	50.90	49.27
90%	66.84	86.53	109.61

Notice how QT (the queueing theory prediction) consistently over-estimates cycle time for the batch arrival system in this example.

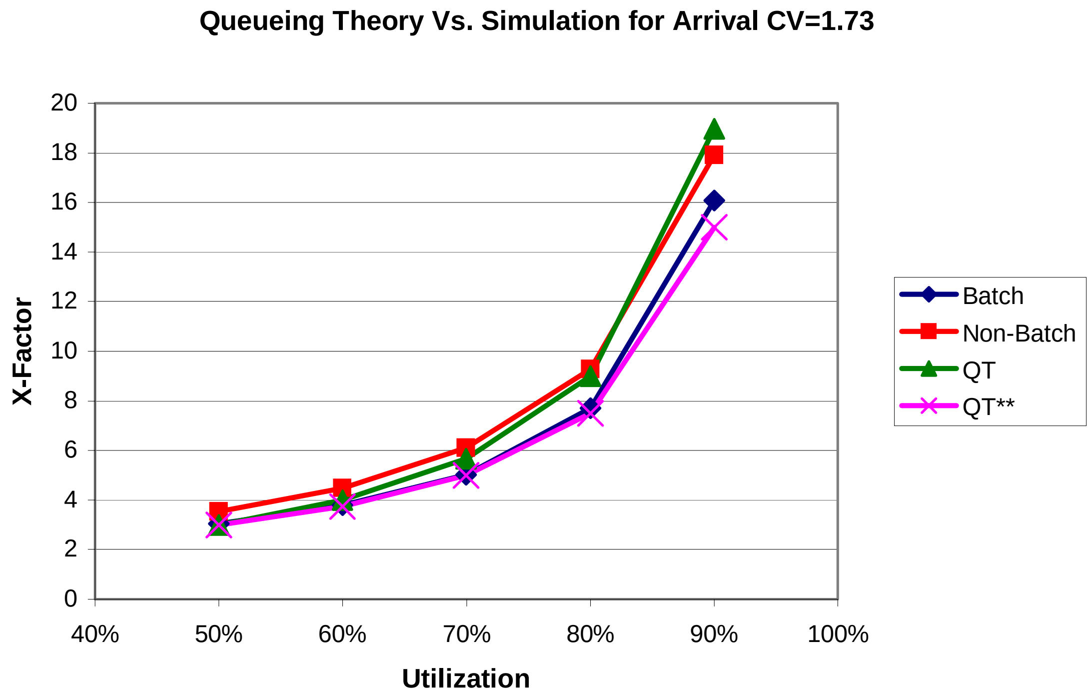
Modification for Batch Arrivals

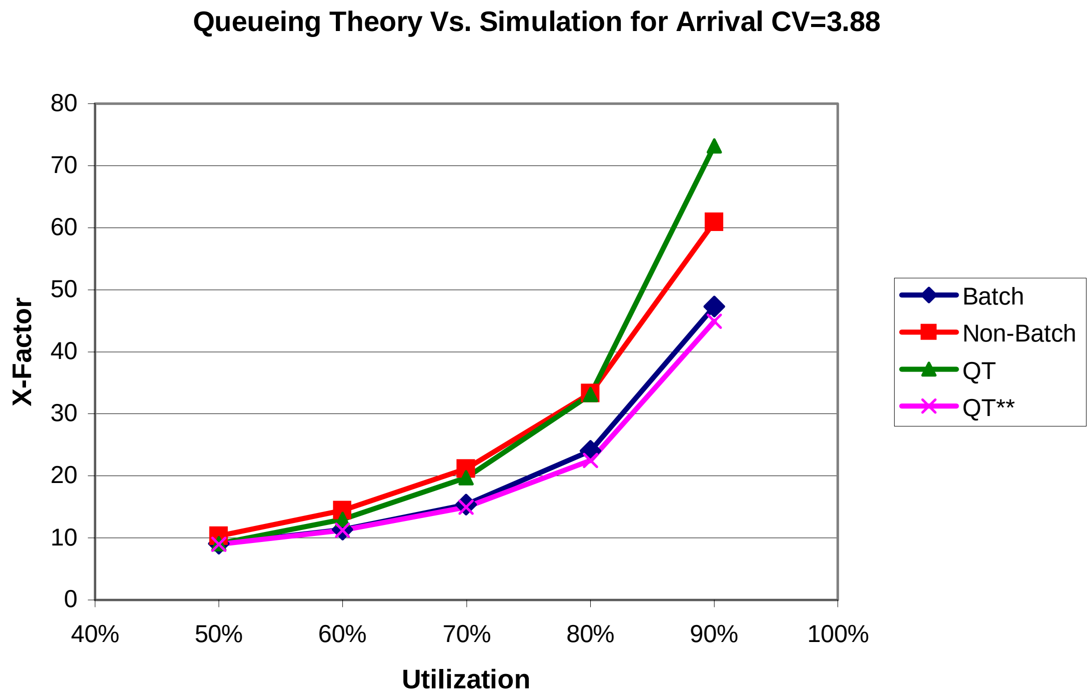
After looking at the above results, we concluded that the queueing theory results in our entitlement calculator needed to be adjusted for the case of batch arrivals (a common situation in wafer fabs). We'll spare you the technical details here (those who are interested can consult the Technical Note below), and just say that we modified our calculator to include additional variables to reflect the arriving batch size and the arriving batch size variability, in addition to the overall arrival process CV. Here arriving batch size variability refers to whether the batches that come are always the same size, or vary from arrival to arrival. When we compared these results to our simulated results, we found that the revised calculator was much more accurate for batch arrivals. The results for all of the arriving batch sizes that we looked at are included below (with graphs of two of the CV values for illustration), where QT** is the revised queueing model.

CV=1.73 [Arriving Batches w/2 lots]

Util.	Batch	Non-Batch	QT	QT**
50%	3.04	3.53	3.00	3.00
60%	3.79	4.48	3.99	3.75
70%	5.03	6.12	5.66	5.00
80%	7.71	9.28	8.99	7.50
90%	16.08	17.90	18.97	15.00

Notice how QT** (the revised queuing theory prediction) more closely tracks the batch arrival results than QT (the original queuing theory prediction) in this table and in the following tables.





CV=2.24 [Arriving Batches w/3 lots]

Util.	Batch	Non-Batch	QT	QT**
50%	4.00	5.11	4.01	4.00
60%	5.02	6.61	5.51	5.00
70%	6.77	9.03	8.02	6.67
80%	10.27	13.50	13.04	10.00
90%	20.33	27.99	28.08	20.00

CV=2.64 [Arriving Batches w/4 lots]

Util.	Batch	Non-Batch	QT	QT**
50%	4.92	6.33	4.98	5.00
60%	6.16	8.28	6.98	6.25
70%	8.24	11.63	10.30	8.33
80%	12.48	18.03	16.94	12.50
90%	27.37	35.33	36.86	25.00

CV=3.88 [Arriving Batches w/8 lots]

Util.	Batch	Non-Batch	QT	QT**
50%	9.06	10.26	9.03	9.00
60%	11.39	14.41	13.04	11.25
70%	15.39	21.13	19.73	15.00
80%	24.06	33.27	33.11	22.50
90%	47.28	60.95	73.24	45.00

CV=4.81 [Arriving Batches w/12 lots]

Util.	Batch	Non-Batch	QT	QT**
50%	12.81	17.80	13.07	13.00
60%	16.00	24.78	19.10	16.25
70%	21.40	34.81	29.16	21.67
80%	33.67	50.90	49.27	32.50
90%	66.84	86.53	109.61	65.00

Explanation

Batched arrivals break the standard queueing model assumption that lot inter-arrival times are independent. In our small set of experiments, breaking this assumption led to queuing theory consistently over-estimating the actual cycle times seen in batch arrival systems. With a bit of work, however, we can modify our original queuing theory model to account for batch arrivals, and this new estimate performs quite a bit better for systems with batch arrivals.

Implications for Estimating Cycle Time Entitlement

If you are using our free operating curve generator (available from www.fabtime.com/charcurve.shtml) or your own queueing models to estimate cycle times for your fab, these results suggest caution if you observe high coefficient of variation values for individual tools or operations. A review of the actual interarrival times for a given tool or operation should give you some idea of whether or not lots are showing up in batches. If not, our preliminary results suggest that you can still use the existing queueing formulas up to about a CV of 3. Above that you should use caution, especially at high utilizations.

If you do observe batch arrivals (and we think that this will be quite common, given upstream batching and transfer batching), then we recommend adjusting your queueing models to account for the batch arrivals, as described in our Technical Note below. We have included this adjustment in our extended FabTime Operating Curve generator. The extended version is available at no charge to fabs that host our cycle time management class, or use our FabTime cycle time management software. We are also modifying our software to report arrival batch size and variability attributes, so that it will be easier for our customers to collect the appropriate data to use in the spreadsheet tools.

Summary

Wafer fabs tend to have high coefficients of variation for arrivals to individual tools and operations. Where these high CVs are due to batch arrivals, caution must be taken before using the values to estimate cycle time entitlement through queueing or spreadsheet models. Batching does dramatically increase the CV of arrivals. However, using the straight CV of arrivals measured for the lot arrival stream in queueing models tended to over-estimate cycle time in our experiments, unless the queueing models are adjusted to account for the arrival batch size. Batch arrivals had less of an impact on cycle time than equally high variability non-batch arrivals, though in all cases, arrival variability increased cycle time.

Closing Questions for FabTime Subscribers

Have you tried measuring arrival CVs for your fab? What type of range of values are you seeing (we will keep individual results confidential)? Is your arrival variability due primarily to batching, or do you see more individual lots arriving?

Further Reading

Factory Physics, by Hopp and Spearman. For a review of this book, see www.FabTime.com/physics.shtml. This book has an excellent discussion on variability.

Technical Note

For details on modeling batch arrivals (G[X]/G/c) using G/G/c approximations, see ‘Stochastic Models of Manufacturing Systems’ (Buzacott and Shantikumar, 1993), page 119-120. The trick is to model each batch arrival as a “super lot” with a longer process time. In the G/G/c approximation, use E[B]E[P] for the average process time and $(C_b^2+C_s^2/E[B])^{(1/2)}$ for the CV of service times, where B is the arrival batch size measured in lots, P is the individual lot process time, and C_b is the CV of arrival batch size. Use the inter-batch arrival CV rather than the inter-lot arrival CV. If you are using our original operating curve generator, remember to multiply the resulting X-factor by E[B], the average batch size, to get a cycle time multiple of E[P] rather than a multiple of E[B]E[P].

The resulting cycle time, call it QT*, will be a better estimate for the batch arrival system, but still needs to be adjusted for the fact that individual lots can leave as soon as they are finished processing. We do not have a reference for the batch adjustment—if you know of one please email us—but here is a quick overview of the calculations. Let P_i be the process time for the i^{th} lot in the arrival batch. Then the process time for the batch is $P_1+P_2+...+P_B$. The expected cycle time for the unadjusted model is given by QT* = E[QueueTime] +E[ProcessTime], where E[ProcessTime] = $E[B]E[P_i]$ (we're assuming the P_i are independent, identically distributed, and independent of B].

However, when lots within an arrival batch do not have to wait for each other to finish, $E[B]E[P_i]$ is too long for the average process time. Instead, we need to calculate the expected process time for a lot that is allowed to leave individually, and then add this to E[QueueTime]. If each lot can leave when it is finished, then Lot 1's process time is P_1, Lot 2's process time is P_1+P_2, etc. And the expected sum of process times for lots in a batch is $E[Sum\{P_i\}] = E[P_i]E[(B+(B-1)+...+1)] = E[P_i]E[B](E[B]+1)/2$ (Here we use the formula for the sum of 1st B integers, although we intend to ask a mathematician to check this). And the expected process time is $E[ProcessTime] = E[P_i](E[B]+1)/2$. So, our adjusted estimate is $QT^{**} = E[QueueTime]+E[P_i](E[B]+1)/2$. To get QT** from QT*, we use $QT^{**} = QT^* - (E[B]-(E[B]+1)/2)*E[P_i] = QT^* - E[P_i]*(E[B]-1)/2$. Or in terms of X-factors (dividing through everywhere by $E[P_i]$), QT**X-factor = QT*Xfactor - (E[B]-1)/2.

If you have questions about this Technical Note, you can contact FabTime's Frank Chance for more information.

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Adexa Corporation (1)
Advanced Micro Devices (34)
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