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THE SHORTEST PROCESSING TIME FIRST (SPTF) DISPATCH RULE AND SOME VARIANTS IN SEMICONDUCTOR MANUFACTURING

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ABSTRACT

Looking for appropriate dispatch rules for semiconductor fabrication facilities (wafer fabs), practitioners often intend to use the Shortest Processing Time First (SPTF) rule because it is said to reduce cycle times. In our study, we show, however, that this positive effect on cycle times can be achieved in single machine systems but not necessarily in complete wafer fabs. In addition, we discuss variants of the SPTF rule.

1 INTRODUCTION

In semiconductor industry, a variety of production control techniques is applied in order to increase throughput, to decrease cycle times, and to achieve on-time delivery of the products (Fowler and Robinson 1995, Wein 1988). Some manufacturers use scheduling approaches but still the majority of the fabs is run under the regime of dispatch rules. With respect to controlling on-time delivery, there are two classes of rules: rules that consider due dates of products, e.g., Critical Ratio (CR) and rules that do not consider due dates, e.g., First In First Out (FIFO). For an overview of dispatch rules typically applied in semiconductor industry see Atherton and Atherton (1995). Looking for simple dispatch rules, the effectiveness of SPTF in wafer fabs is often discussed.

SPTF is simple because lots waiting for a resource a ranked according to their processing time at this particular resource. The lot with the shortest processing is going to be processed first. This rule originally came from computer operating system (OS) design where the goal was to keep the number of jobs waiting for the processor as low as possible. In this environment the rule proved to be quite effective. Hence, the question arises whether the same degree of effectiveness can be achieved in a wafer fab. There are a number of differences between a computer OS and a wafer fab both with respect to the jobs and the resources. In an OS, the processing times of the jobs vary over a wide range whereas in wafer fabs lots of one product at a particular processing step have the same processing time. With respect to the resources, in an OS we have to consider one or more resources in parallel at one stage but in a wafer fab we have a multi-stage system of parallel resources.

In our study, we compare the cycle times (CT) of a single stage system and a wafer fab using SPTF dispatch. In addition, we investigate these systems under the regime of the following modifications of the SPFT rule:

- SPTF and absolute waiting time limit (AWTL): lots waiting longer than a specified limit are ranked in FIFO order in front of the lots that are not yet exceeding the limit.
- SPTF and mean waiting time limit (MWTL): lots waiting longer than a multiple of the average waiting time of all lots are ranked in FIFO order in front of the lots that are not yet exceeding the limit.
- FIFO or SPTF according to queue length (FSQL): as long as the number of lots is below a given queue length limit FIFO is used. If this threshold is exceeded SPTF is used.

The remainder of the paper is organized as follows. Section 2 discusses the simulation results of a single stage system. Section 3 provides the results for a complete wafer fab simulation model. Section 4 summarizes the findings.

2 SINGLE STAGE MODEL

As a single stage model, we use a model with exponentially distributed interarrival times and exponentially distributed processing times of the lots and a single resource. This model is also known from queuing theory as M/M/1 model (Kleinrock 1975). We have two products, product A with an average processing time of 0.6 hours and product B with an average processing time of 0.1 hours. We consider the following product mixes: 25%/75%, 50%/50%, and 75%/25%.

In the following, we present the cycle time results for this model under the regime of the first two SPTF-based dispatch rules mentioned above.

2.1 SPTF and Absolute Waiting Time Limit

The SPTF-AWTL rule degenerates to FIFO for a waiting time limit of 0 hours and to SPTF for large maximum waiting times. In our case, a waiting time limit of 17 hours was large enough to make the SPTF-AWTL curves undistinguishable from the SPTF curves.

From a first series of simulation runs, we concluded that for the single stage model the product mix has only little effect on the principal behavior of the results. In the following we therefore only show curves for the 50%/50% case.

Figure 1 shows the average cycle times of the lots for a utilization ranging from 70 to 95%.

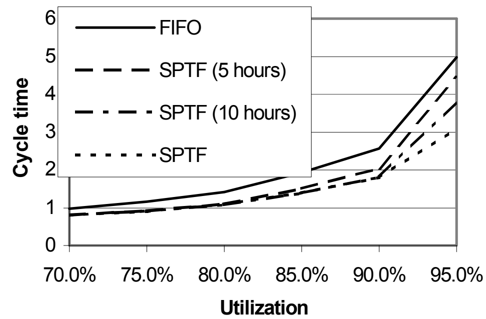

Figure 1: Average Cycle Times for SPTF-AWTL

As expected, SPTF shows the best cycle time performance and FIFO the worst. The SPTF-AWTL curves lie between these two curves ordered according to their waiting time limits 5 hours and 10 hours.

For product A with the small processing time average the Coefficient of Variation (CoV) curves almost match (Figure 2). In addition, the CoV is only slightly increased for higher loads.

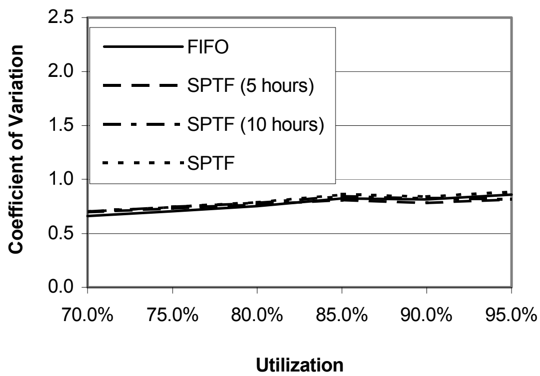

Figure 2: CoV of Cycle Times for Product A

For lots of product B the CoV behavior depends considerably on the dispatch rules and their parameters (Figure 3). During classical SPTF dispatch we observe the lowest CoV values. The FIFO values are about twice as large, i.e., the application of SPTF reduces the variability of the production process for type B lots.

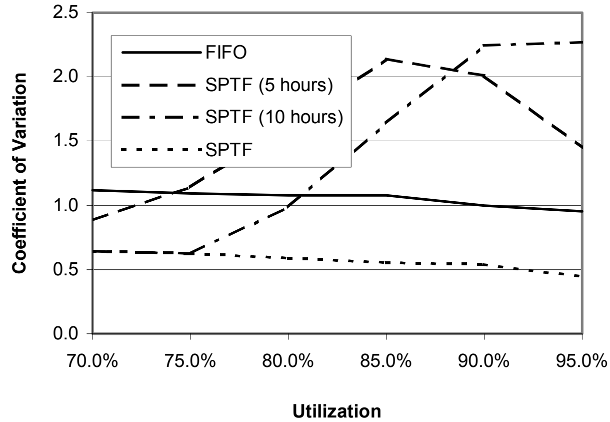

Figure 3: CoV of Cycle Times for Product B

Adding a waiting time limit to the SPTF rule has a negative effect on the CoV values for lots with larger average processing times. The sudden reranking of the lots upon reaching a given waiting time limit leads to an increased variability of the considered single stage system.

2.2 SPTF and Mean Waiting Time Limit

The SPTF-MWTL rule degenerates to FIFO if the waiting time limit is 0x the mean waiting time of all lots waiting for service. For a limit of above 10x the mean waiting time the curve becomes indistinguishable from the SPTF results.

Figure 4 depicts the average cycle times for all lots under the regime of SPTF-MWTL dispatch.

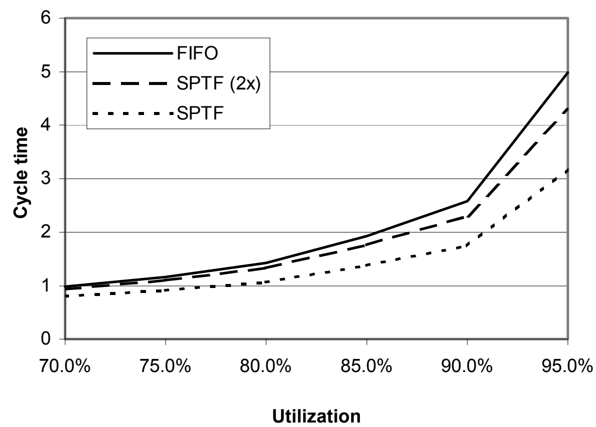

Figure 4: Average Cycle Times for SPTF-MWTL

The SPTF-MWTL curves lie between the SPTF and FIFO curve, respectively.

As for the SPTF-AWTL case (Figure 2), the product A CoV values almost match (Figure 5).

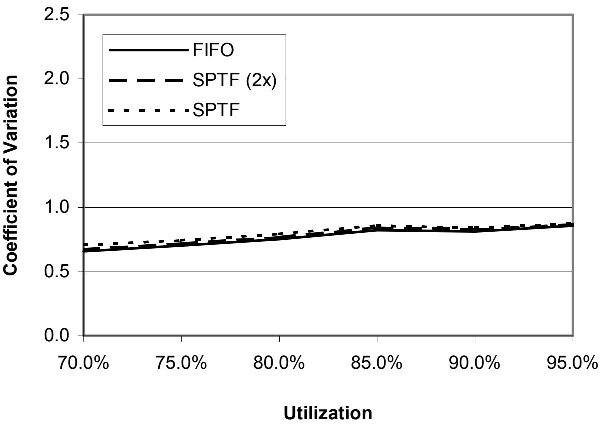

Figure 5: CoV of Cycle Times for Product A

Using SPTF-AWTL dispatch, the CoV values of product B lots remain between the FIFO and SPTF curves besides for a few exceptions, where they are slightly higher than the FIFO curve (Figure 6).

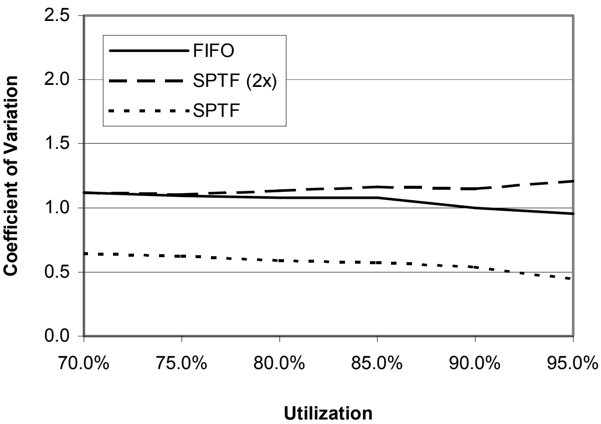

Figure 6: CoV of Cycle Times of Product B

2.3 Summary

For a single stage M/M/1 system and two products with different average processing times classical SPTF leads to a considerable reduction of average cycle times and the CoV of the cycle times. With respect to average cycle times, the modified rules SPTF-AWTL and SPTF-MWTL lead to results lying between classical SPTF and FIFO depending on the parameter setting. Concerning the CoV of the cycle times, only SPTF-MWTL leads to acceptable results because SPTF-AWTL may considerably increase the CoV values of the product with the longer average processing time.

3 WAFER FAB MODEL

After testing the dispatch rules in a single stage model, we implemented them in full wafer fab model. As test model we use the MIMAC (Measurement and Improvement of MAnufacturing Capacities) testbed dataset 6. Details can be found at <www.eas.asu.edu/~masmlab>.

For the simulation runs, we used Factory Explorer 2.6 from WWK. The modified SPTF rules were added to the built-in dispatch rules by means of user rules implemented in C code.

We intended to use the same rules for all workcenters of the set 6 fab without changing the given product mix to obtain a clear picture of the effects of the dispatch rule parameters. Unfortunately, it turns out that even for a utilization of 80% the SPTF runs become unstable. This behavior is caused by a batch machine, 11026_ASM_B2. As soon as we change the dispatch rule of this particular machine to FIFO the runs become stable. All wafer fab experiments were performed using this setting for machine 11026_ASM_B2.

3.1 SPTF and Absolute Waiting Time Limit

We conducted a series of experiments with a variety of waiting time limits ranging from 1 hour to 30 hours. For products B6HF, C5F, C5P, C5PA, C6N2, and C6N3, there were no significant changes in the average cycle times for the different dispatch rules.

The curves for the products OX2 (Figure 7) and C4PH, however, show a considerable increase in cycle time if the dispatch rule is changed from FIFO to SPTF. The values for SPTF-AWTL lie between these two curves.

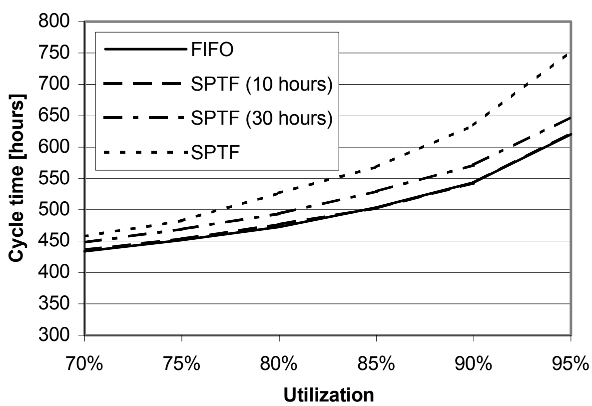

Figure 7: Average Cycle Times for Product OX2

The same holds for the Coefficient of Variation of the cycle times. Figure 8 presents the CoV curves of product OX2.

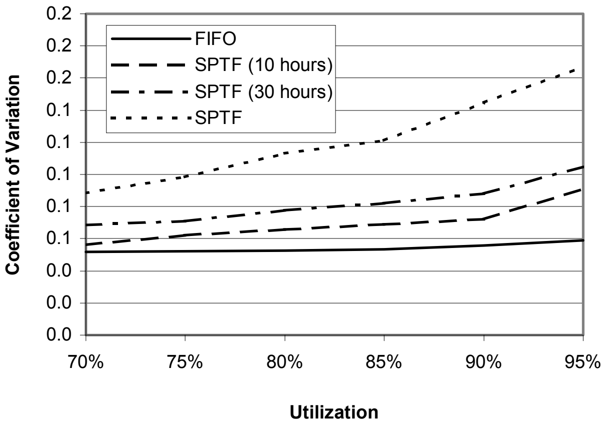

Figure 8: CoV of Cycle Times for Product OX2

Product B5C lots, however, show the behavior expected from the single stage experiments (Figure 9). Here, cycle times decrease if we switch from FIFO to SPTF dispatch.

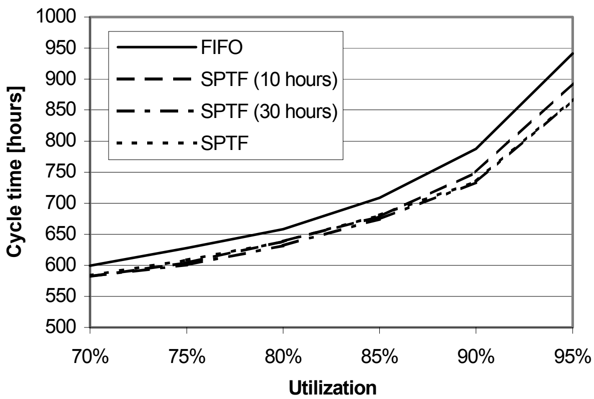

Figure 9: Average Cycle Times for Product B5C

Experiments with the SPTF variant SPTF-MWTL provide similar results. For most of the products there are no changes in cycle time if FIFO is replaced by SPTF-MWTL. For OX2 and C4PH, the cycle time increases. It decreases for product B5C.

3.2 SPTF/FIFO Switching According to Queue Length

For the SPTF variants tested so far the effect on cycle times compared to the FIFO case depends on the products' recipes and the product mix. Unfortunately, the direction of change in cycle time by replacing FIFO dispatch is not predictable.

Thus, we study the effects on cycle times when a different approach (FSQL) is used to dispatch the lots in queue. FIFO is used if the number of lots waiting is less than a given limit. As soon as this limit is reached SPTF dispatch is applied. For a queue length limit of 0 this rule degenerates to SPTF, for large values it results in FIFO dispatch.

Again, the cycle time behavior is almost identical to the SPTF-AWTL case. Figure 10 depicts the average cycle times of product C4PH

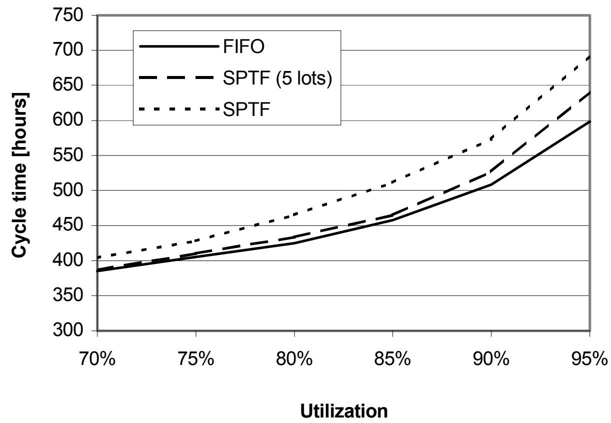

Figure 10: Average Cycle Times for Product C4PH

The CoV of the cycle times of product C4PH also increase if we switch from FIFO to SPTF (Figure 11). The curves for the different queue levels lie between these two curves.

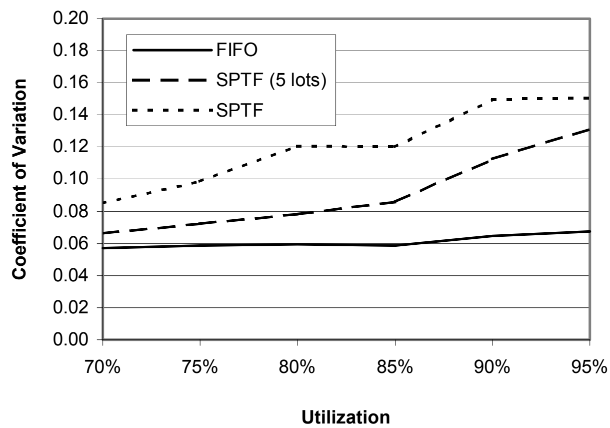

Figure 11: CoV of the Cycle Times for Product C4PH

3.3 Summary

In the considered wafer fab model it was not predictable what happens if the dispatch rule is changed from FIFO to SPTF. For a few products the cycle time decreased as intended but for most of the products there was almost no change in cycle times. It even happened that cycle time increased for some products. All tested SPTF variants lead to cycle time results lying between those of FIFO dispatch and classical SPTF dispatch.

To explain this behavior, we looked closer at the effect of the SPTF rule on the ranking of the lots waiting in front of a workcenter. In contrast to the M/M/1 case discussed in Section 2, processing times in a wafer fab are not random. Hence, SPTF results in a local priority scheme. Due to different processing times at different steps of the recipes, these priorities change from workcenter to workcenter. As a consequence, the effect of using SPTF in a multi-stage environment of that type is not predictable. It depends both on the recipes and the product mix. We made slight changes in the product mix and the cycle time results were considerably different from those presented above. Some products became faster, some of them slower.

Using SPTF only for a small set of workcenter merely reduces the magnitude of the changes but not the effect as such.

4 CONCLUSION

In this paper, we consider SPTF dispatch and some of its variants. We apply the rules to both a single stage model and a wafer fab model. The single stage model behaves as expected: there is a considerable reduction in cycle times if the dispatch rule is changed from FIFO to SPTF. The parameter of the SPTF variants can be used to control the magnitude of this change.

For the wafer fab model, however, it turned out that the effect of changing the dispatch rule from FIFO to SPTF was not predictable. For some products the cycle time increased, for some products it decreased but for most of the products there was no significant effect.

This effect was caused by the way SPTF ranks the lots. Due to the fact that processing times of lots at particular steps of the recipes are constant, SPTF results in a local priority scheme. These schemes, however, change from workcenter to workcenter. As a consequence, the effect of using SPTF depends both on the products' recipes and the product mix. Thus, it is practically impossible to predict direction and magnitude of the change in cycle time.

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