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SOME ISSUES OF THE CRITICAL RATIO DISPATCH RULE IN SEMICONDUCTOR MANUFACTURING

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ABSTRACT

In this paper, we examine the cycle time and on-time delivery performance of a semiconductor wafer fabrication facility (wafer fab) under critical ratio (CR) dispatch regime. It turns out that determining appropriate due dates for this rule is a critical task. We provide a detailed analysis of the wafer fab behavior for a large range of due date values. From the results of the experiments we develop a heuristic for conservative due date estimates.

1 INTRODUCTION

In semiconductor industry, a variety of production control techniques are 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 are 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) or Earliest Due Date (EDD) and rules that do not consider due dates, e.g., First In First Out (FIFO) or Shortest Processing Time First (SPTF) (Rose 2001). For an overview of dispatch rules typically applied in semiconductor industry see Atherton and Atherton (1995). Looking for simple dispatch rules, the effectiveness of CR in wafer fabs is often discussed.

2 SIMULATION EXPERIMENTS

There are different implementations of the CR dispatch rule that can be found in the literature and in simulation packages.

- (1 + Due - Now) / (1 + TRPT), if Due > Now, and 1 / ((1 + Now - Due) * (1 + TRPT)), otherwise.
- (Due - Now) / (1+ TRPT),

where Due is the due date of the lot, Now the current time, and TRPT denotes the total remaining processing time. In both cases the lot with the lowest CR value is chosen for processing. We prefer the first alternative because it showed better performance results in our simulation studies so far.

The most important decision when applying CR is how to set the lot due dates. In a real fab situation the planning department usually provides the due date. In our case, however, we were interested in whether there is a due date setting that minimizes the average cycle times of the lots.

In general, the due date for a lot of a specific product is given in terms of a flow factor (FF) that is defined as the target cycle time divided by the raw processing time (RPT). For instance, an FF of 2 says that a lot spends half of its cycle time in processing state and the other half in non-processing states like waiting. Thus, the due date of a lot is the time when it enters the fab plus FF times RPT.

To avoid the explosion of the parameter space for the simulation experiments we decided to use the same flow factors for all lots. Moreover, it is hard to decide from an academic viewpoint which FF values should be given to which products without knowing the requirements and constraints of a real planning department.

As test models we used the MIMAC (Measurement and Improvement of MAnufacturing Capacities) test bed datasets 1, 3, 4, 5, 6, 7. Dataset 2 was not used because the simulation package reported problems in the dataset. Table 1 shows the basic properties of the model fabs.

Table 1: MIMAC Datasets

Fab	Tool Groups	Tools	Products	max. Steps
1	83	265	2	245
3	73	354	11	547
4	35	69	7	92
5	85	176	21	266
6	104	228	9	355
7	24	38	1	172

For further details on the datasets and their download: see <`www.eas.asu.edu/~masmlab`>.

The simulation runs were carried out with Factory Explorer 2.6 from WWK. We simulated 7 years of fab operation. The first two years were considered as warm-up phase and not taken into account for the statistics. We checked the length of the initial transient both by the cycle time over lot exit time charts and the Schruben test. If there was an indication of initial bias problems the warm-up phase was increased appropriately. The measurement interval was 5 years in all cases.

For all 6 test bed models we simulated the following dispatch regimes: FIFO (as reference) and CR with FF ranging from 1.0 to 3.5 in steps of 0.1.

3 SIMULATION RESULTS

The first part of the results section presents the average cycle time results for all lots. The second part considers the on-time delivery percentages of the lots. Low cycle times and high on-time delivery percentages are conflicting goals. To finish a lot before its due date often has the consequence that other lots have to wait longer than in the FIFO case due to the priority scheme established by CR. This leads to an increase in cycle time. Good on-time delivery performance is in most cases not available for free.

With respect to the cycle time results, the datasets can be divided into two groups. Fabs 1, 3, 5, and 6 show behavior like Figure 1 and Fabs 4 and 7 like Figure 2. In both figures we present average cycle times of all products over the FF used for the CR dispatch rules. The emphasized lines provide the CR results and the dashed lines the FIFO reference values. The fab load was as follows: 70% for the bottom lines, 84% for the middle lines, and 98% for the top lines, respectively.

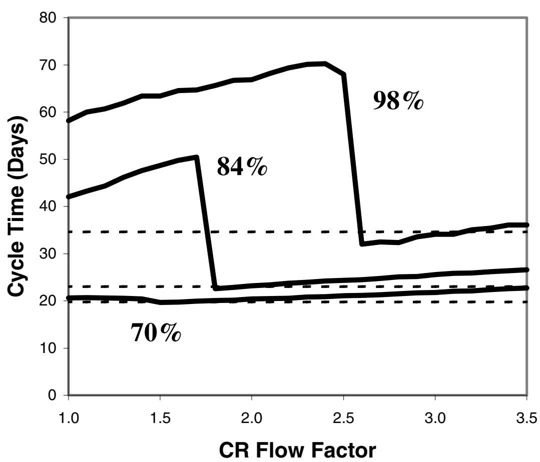

Figure 1: Fab 6 Under CR Regime

If we consider the 98% curve in Figure 1 we notice that the cycle times grow up to an FF of 2.5 and then suddenly drop below the FIFO curve for an FF of 2.6. For larger FF values the cycle times grow again above the FIFO reference line. For lower loads, the drop in average cycle time occurs earlier and is smaller. It is worth noting that in all three load cases there are only a few FF values that lead to cycle times lower than in the FIFO case. In addition, the optimal FF value depends on the fab load. For instance, if we set the FF to 2.6, i.e., the 98% optimum, this value leads to cycle times that are worse than in the FIFO case for loads less than about 90%. If we choose 1.8, the 84% optimum, this causes about twice the cycle time compared to the FIFO case at a load of 98%. As a consequence, it will be hard to set the CR due dates in a way that stable and reliable fab operations are possible. In the next section will we discuss the reasons for the shape of the curve in more detail.

Figure 2 depicts the cycle time curves for a fab that shows little reactions on changes in due dates. There is only a slight increase if we increase FF. In this case CR does neither improve nor considerably deteriorate the fab performance. We assume that Fabs 4 and 7 are too small to show the dramatic effects of the fabs.

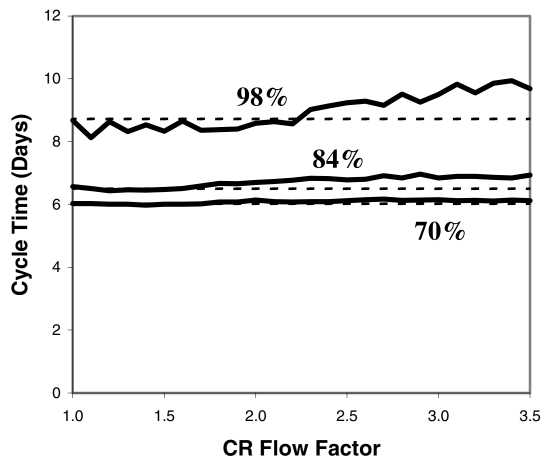

Figure 2: Fab 4 Under CR Regime

In Figure 3 we compare the on-time delivery performance of CR and FIFO. The emphasized lines provide the CR results and the dashed lines the FIFO reference values. The fab load was as follows: 70% for the left lines, 84% for the center lines, and 98% for the right lines, respectively.

In all three load cases CR on-time delivery percentages jump almost immediately from 0% to 100% as soon as the FF average cycle time optimum is passed. With respect to meeting the due dates CR clearly outperforms FIFO if FF is set adequately. For instance, for a load of 98% and an FF target of 2.6, all lots leave the fab before due date under CR regime whereas 45% of the lots are late in the FIFO case.

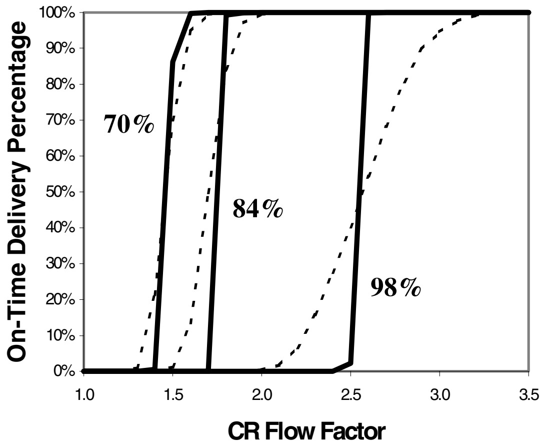

Figure 3: Fab 6 On-time Delivery Performance

To guarantee an on-time delivery percentage of 100%, CR is a safe choice if the FF value is larger than the critical limit.

4 IN-DEPTH ANALYSIS

In the following we present a detailed analysis of the Fab 6 cycle time behavior under CR dispatch regime.

First, we tried to find a link between the FIFO cycle times and the FF value where the CR cycle time drops below the FIFO line. Table 2 indicates that for Fab 6 CR shows its best performance for a given load if the corresponding FF is just above the average cycle time of the FIFO case given in multiples of the RPT.

Table 2: FIFO vs. CR (Fab 6)

Load	FIFO Avg. Cycle Times	CR Best FF
70%	1.5	1.5
77%	1.6	1.7
84%	1.7	1.8
91%	2.0	2.1
98%	2.6	2.6

The same correlation can be found for Fab 3. For Fab 1 the best FF values are close to the cycle time medians. In the case of Fab 5 the CR effects are smaller than for the other fabs and no significant relationship was present.

Next, we try to identify the tools that cause the drop in cycle time from FF 2.5 to 2.6. Two important fab charts support this search: the “bottleneck tool group chart” and the “cycle time contribution by tool group chart”. Under 98% fab load, the 11026_ASM_B2 furnace is the main contributor to the cycle time, both in the FIFO and CR FF 2.5 case. Using FIFO the furnace consumes 19% of the cycle time whereas it amounts to 59% under CR regime. Note that in both cases this batch tool is not the bottleneck. We first considered capacity loss due to batching as a possible reason for the huge increase in cycle time but it turned out that the batch utilization was about 93% in both cases.

To increase the level of analysis detail one step further we have to consider the cycle time contribution by process step. Table 3 shows cycle times averages in hours for single simulation years of the 11026_ASM_B2 processing steps for product 38090964_B5C in the FIFO case. Years 6 and higher have approximately year 5 values.

Table 3: Process Step Details (FIFO)

Step	Batch ID	Year 3	Year 4	Year 5
10701_O1201	3	32.71	40.42	44.13
12701_O1201	3	32.79	40.16	43.78
12811_O1201	3	32.72	40.58	43.5
16001_O1201	3	32.33	39.96	43.83
25561_O3102	32	26.3	33.43	37.33

A product B5C lot is visiting the furnace 5 times. The first 4 visits have the same batch IDs and the same processing times. As a consequence, the cycle times are about the same. The 5th step has a smaller processing and cycle time. In the FIFO case lots with the same batch ID are processed together. No additional constraints are considered.

Table 4 shows the corresponding cycle times for the CR 2.5 case.

Table 4: Process Step Details (CR 2.5)

Step	Batch ID	Year 3	Year 4	Year 5
10701_O1201	3	46.8	126.29	818.14
12701_O1201	3	7.86	8.21	8.45
12811_O1201	3	7.5	7.87	8.07
16001_O1201	3	7.64	7.75	7.93
25561_O3102	32	20.16	16.76	10.93

Here, the picture is very different to the FIFO table. The first step takes considerably more time than the other steps; in year 5 the cycle time is one hundred times larger than steps 2 to 5. After year 5 the cycle times for all 5 steps remain almost constant.

What happened? During warm-up more and more lots enter the fab and the average cycle time increases because of the increase of waiting times at the tools. In front of highly loaded machines the lots experience more waiting times. In addition, tools break down and the CR value of the lots shrinks again. Because of the fact that the due date for the lots is less than the average FIFO cycle time, a considerable number of lots tend to become late. The CR rule assigns higher priorities to these lots to speed them up. Then, fresh lots have to wait. Because of the large amount of lots with higher priority they are using up their slack time to the due date while still being in the first part of their route. The waiting time at the first furnace step grows up to a certain balance threshold. From that moment on the fab is stable but operating at a very high inventory and cycle time level. This is a behavior that we already predicted based on a simple fab model (Rose 1998).

We found another indication for this negative effect of CR on the cycle times in one of our Fab 6 simulations runs. Figure 4 shows the cycle time over lot exit time for an FF 2.5 experiment at 98% fab load.

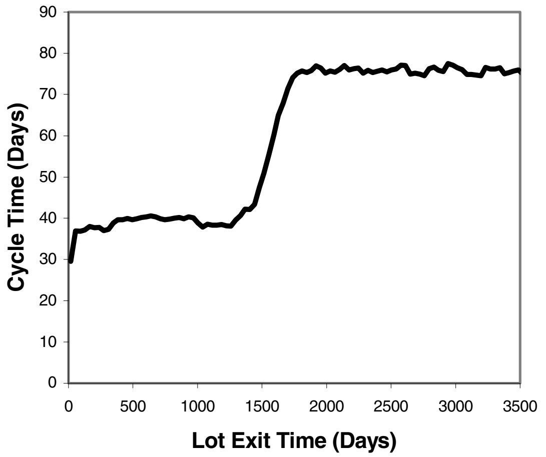

Figure 4: Cycle Time Evolution (Fab 6, CR 2.5)

The fab seems to become stable at a cycle time average of about 40 days. But after about 1400 days of simulation a longer breakdown happens at the furnace. This is the missing stochastic kick cycle time average needs to loose this temporal stability and to start to grow again to its final level. Again, this shows that the combination of CR with low FF values, high fab loads, and machine failures at important machines lead to a fab state that is difficult to control.

5 QUICK SOLUTION APPROACH

We intended to find a simple way to avoid the instability of the fab under CR 2.5 regime.

Our approach was to change the furnace dispatch rule from CR to FIFO. Table 5 shows the cycle time in days for this experiment.

For loads up to 91% the differences are not significant and FIFO outperforms the other rules. Under a load of 98% our simple CR replacement approach was successful. The average cycle time decreases from 71.4 days to 39.1 days that is close to the FIFO value. This indicates that there might be simple strategies to avoid the hazards of the application of CR dispatching.

Table 5: Cycle Time in Days (Fab 6)

Fab Load	CR 2.6	FIFO	CR 2.5 + FIFO	CR 2.5
70%	21.2	19.7	20.1	21.0
77%	22.5	20.9	21.6	22.5
84%	24.5	23.0	24.0	24.4
91%	27.2	26.4	27.2	27.0
98%	32.0	34.6	39.1	71.4

But if we consider the on-time delivery values in Table 6, we notice that the CR by FIFO replacement does not lead to an improved result in this performance measure, too.

Table 6: On-time Delivery Percentages (Fab 6)

Fab Load	CR 2.6	FIFO	CR 2.5 + FIFO	CR 2.5
98%	99.9	40.3	0.0	2.3

After the change no lots leave the fab before the FF 2.5 due date. Even in the FIFO case there was a considerable amount of lots on time. As a consequence the quick fix does not lead to a real improvement of the situation. The only way to improve the results is to increase the FF for the CR dispatch rule.

6 CONCLUSION

This paper showed that setting the due dates for the critical ratio (CR) dispatch rule is not straightforward.

From the results of the simulation experiments performed in the course of this study we suggest the following heuristic procedure to find a conservative flow factor (FF) value for CR. First, one has to perform simulation runs under FIFO regime at high fab loads, say 98%. From the results, the average cycle times are obtained. The FF for the CR dispatch rule can now be computed from this value divided by the average RPT plus a small safety buffer constant, say 0.1 or 0.2.

If the FF is set smaller than the heuristic value there is a considerable risk that the fab does not perform well both in terms of cycle time and on-time delivery.

The only drawback of this approach is that the average cycle times of a lot will be higher for a wide range of fab loads compared to FIFO dispatch. At this point, there is a trade-off between high on-time delivery percentages and low average cycle times. In our experiments, however, the increase in average cycle time due to CR dispatching tended to be rather small.

In a future study, it may be rewarding to overcome the restriction of a global FF value for all products. For a real planning department it is of interest to obtain rules of thumb for good per product FF values.

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