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A COMPOSITE RULE COMBINING DUE DATE CONTROL AND WIP BALANCE IN A WAFER FAB

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ABSTRACT

Different single dispatching rules aim at different objectives, for instance, SPT (shortest processing time) rule is good at minimizing cycle time and ODD (operation due date) rule intends to minimize deviation between lateness and target due date to achieve better on-time delivery. While some advanced rules called composite rules combine the characteristics of those basic single rules into one composite dispatching rule such as MOD (modified operation due date) which is a combination of SPT and ODD rule. In this paper, a new composite rule which combines ODD, SPT and LWNQ rules (least work at next queue) is developed with the objective of due date control and workload balance. A design of experiment is used to determine the appropriate scaling parameter for this composite rule. The simulation results show significant improvement versus the use of MOD rule.

1 INTRODUCTION

During the past 30 years, a number of researchers have investigated the performance of various dispatching rules for semiconductor industry. We refer the interested reader to (Atherton and Atherton 1995) for details. Different single dispatching rules have different performance objectives. Some rules target at minimizing the cycle time like SPT (shortest processing time). Some rules target at due date control to achieve a good on-time delivery and tardiness like ODD (operation due date). While some advanced rules called composite rules combine the characteristics of those basic single rules into one composite dispatching rule such as MOD (modified operation due date) and ATC (apparent tardiness cost). MOD (Baker and Bertrand 1981) rule is combination of SPT and ODD. It performs like SPT if target due date is tight and like ODD if target due date is loose. For each lot in the queue of a work center at time t MOD is calculated in the following way: $P = Max\ (ODD,\ t + PT)$ where ODD is the operation due date of lot at work center, t is current time and PT is the processing time of lot at work center. The MOD rule gives priority to the lot with the smallest value of P. MOD rule tends to combine advantage of SPT and ODD and provides a short cycle time and good on-time delivery working with different target due date simultaneously. In a composite rule, each basic single rule has its own scaling parameters which is chosen appropriately to determine the contribution of the basic rule to the composite rule, and that is the difficult part in using composite rules.

The MOD rule generally solves the problem that overemphasizing due date control with tight target due dates causes WIP (work in process) imbalance to certain extent. However, when the fab is running under high capacity loading, WIP imbalance can still happen especially if the machine has a breakdown. In our previous study (Zhou and Rose 2010), we noticed that WIP balance with the viewpoint of machine achieves cycle time reduction. No literature has reported the complementary strength of due date control and WIP balance. Therefore, a composite rule combining ODD, SPT and LWNQ (least work at next queue) is developed. The LWNQ is a simple workload control rule which looks at WIP balance with the viewpoint of machines. The lot that is to be processed by the next machine with least production hours remaining gets the highest priority among the waiting lots. The objective of this study is to introduce influence of LWNQ when the target due date varies between tight and loose under high capacity loading, to see whether cycle time and on-time delivery can get improved further simultaneously versus only the use of MOD case. As we mentioned above, how to determine the proper scaling parameters is the key to apply a composite rule. In this study, three parameters with different three levels are pre-determined and a design of experiment is used to acquire suitable levels for the parameters.

This paper is organized as follows. In Section 2, we describe the proposed composite rule in detail. In Section 3, we present and compare the simulation result with MOD case. Section 4 gives a conclusion.

2 THE COMPOSITE RULE COMBINING DUE DATE CONTROL AND WIP BALANCE

2.1 Ranking Expression

This composite rule is a ranking expression combining ODD, SPT and LWNQ, and described as follows. Each single rules has its own scaling parameter determining the contribution of itself to the total ranking expression. In this rule an index value is calculated for each lot and the lot with lower index value is favored.

$$I(i,t) = \frac{ODD}{P1} + \frac{PT + Now}{P2} + \frac{LWNQ}{P3} \tag{1}$$

Where *I(i,t)* represents the index value of lot *i* at time *t*, *ODD* is the operation due date value of lot *i*, *PT* is the processing time of lot *i*, *LWNQ* is the remaining production hour of the machine at which lot *i* is processed next, *Now* is the current time. *P1*, *P2* and *P3* are the scaling parameters.

Those three scaling parameters should be related to the due date and tardiness of lot, workload of upstream and downstream machine, so as to determine the contribution of basic rule. The following are other factors designed to determine *P1*, *P2* and *P3*.

- MOD factor: *M = Due(i, op) / (PT(i) + Now)*.
- Due date tightness factor: *T1 = 1 – Due(avg, final) / (Workload + Now)*.
- Due date tightness factor: *T2 = 1 – Due(avg, op) / (Workload + Now)*.
- Tardiness factor: *Tar1 = Tardiness(i) / Tardiness(avg)*.
- Tardiness factor: *Tar2 = Tardiness(i) / MaxTardiness(down)*.
- Slack time ratio factor: *S = (Due(i, op) - Now) / (Due(i, final) - Now)*.

Where *Due(avg, final)* is the average final due date of lots, *Due(avg, op)* is the average operation due date of lots, *Tardiness(i)* is the tardiness of lot *i*, *Tardiness(avg)* is the average tardiness of all lots in the queue, *MaxTardiness(down)* is the maximum tardiness in the downstream machines which lot *i* is heading towards, *Due(i, op)* is the operation due date of lot *i*, *Due(i, final)* is the final due date of lot *i*, *PT(i)* is the processing time of lot *i*, *Workload* is the remaining production hours of machine in which lot *i* is queuing, *Now* is current time.

The factor *M* originates from MOD rule. It decides whether ODD rule dominates over SPT rule or vice versa, working with different target due date. *T1* represents the final due date tightness of lots. If *T1* is large, the average final due date is small, and most of the lots seem to be tardy for their final due date. Conversely, if *T1* is small, the average final due date is large, which means most of the lots are likely completed on time. *T2* has the same meaning as *T1*, the difference lies in that *T2* considers the average operation due date for lots. If *T2* is large, which demonstrates that most of lots seem to be tardy for the due date of operation and vise versa. *T2* is more sensitive than *T1*, since operation due date considers due date for all intermediate operation, it reflects more precisely than final due date regarding tardiness problem, e.g., on schedule or tardy. $Tar1$ is the measure of tardiness emergency in the queue. The larger the $Tar1$ is, the more tardy the lot is. Different from $Tar1$, $Tar2$ calculates whether the tardy lot has opportunity to be speeded up to next operation to catch up with the due date. If $Tar2$ is larger than 1, which means the tardiness in the downstream machines for the lot is less serious than in the current machine. The lot probably needs to be accelerated to the downstream machine for the next operation. The factor S measures the slack time ratio between operation due date and final due date.

2.2 Design of Experiment

There are three scaling parameters $P1$, $P2$ and $P3$ which are considered as factors. In this study, each factor has three different levels as show in Table 1. Therefore, a full factorial design with 27 possible combination is applied to figure out which level combination can achieve better performance.

Table 1: Design of experiment for the scaling parameters determination.

Factors	$P1$	$P2$	$P3$

Level 1	If (M>=1)
	$P1$=1
	Else
	$P1$ = 8*M
		If (M>=1)
		$P2$=8*M
		Else
		$P2$ = 1
			If ($Tar1$>=1)
			$P3$=$Tar1$
			Else
			$P3$=1/$Tar1$

Level 2	If (M>=1)
	$P1$=1+$T1$ for $T1$<=0.3
	$P1$=2-$T1$ for $T1$>0.3
	Else
	$P1$=4.5+$T1$ for $T1$<=0.3
	$P1$=6-2*$T1$ for $T1$>0.3
		If (M>=1)
		$P2$=4.5+$T1$ for $T1$<=0.3
		$P2$=6-2*$T1$ for $T1$>0.3
		Else
		$P2$=1+$T1$ for $T1$<=0.3
		$P2$=2-$T1$ for $T1$>0.3
			If ($Tar2$>=1)
			$P3$=$Tar2$
			Else
			$P3$=1/$Tar2$

Level 3	If (M>=1)
	$P1$=1.5+$T2$ for $T2$<=0.5
	$P1$=3-$T2$ for $T2$>0.5
	Else
	$P1$=5.5+$T2$ for $T2$<=0.5
	$P1$=7-2*$T2$ for $T2$>0.5
		If (M>=1)
		$P2$=5.5+$T2$ for $T2$<=0.5
		$P2$=7-2*$T2$ for $T2$>0.5
		Else
		$P2$=1.5+$T2$ for $T2$<=0.5
		$P2$=3-$T2$ for $T2$>0.5
			If (0<=S<1)
			$P3$=4+S
			Else If (S>=1)
			$P3$=- (S+2)
			Else
			$P3$= 4+$\lvert S\rvert$

2.3 Simulation Model

The small whole wafer fab dataset MIMAC6 from Measurement and Improvement of MAnufacturing Capacities (MIMAC) (Fowler and Robinson 1995) is used to test the composite rule. MIMAC6 is a typical complex wafer fab model including:

- 9 products, 9 process flows, maximum 355 process steps.
- 24 wafers in a lot. 2777 lots are released per year under fab loading of 100%. All lots have the same priority of 1 when they are released in the fab.
- 104 tool groups, 228 tools. 46 single processing tool groups, 58 batching processing tool groups.
- Setup avoidance, rework, MTTR (mean time to repair), and MTBF (mean time between failures) of tool group.

The simulation experiments are carried out with Factory eXplorer (FX) from WWK. The proposed composite rule is not provided by the FX simulation package, but FX supports customization via a set of user-supplied code and dispatch rules.

3 SIMULATION RESULTS AND PERFORMANCE ANALYSIS

Firstly we considered the fab is running with a tight target due date and 95% capacity loading case. The target due date flow factor was set to 1.5 to the product, which means all products tend to be tardy. In

MOD rule, SPT play a more important role than ODD with this tight target due date. By noticing this, the LWNQ rule was introduced to play second role in this composite rule. This is the reason why the scaling parameters were set in Table 1. The simulation length of MIMAC6 was carried out for 18 months. The first 6 months were considered as warm-up periods, and not taken into account for statistic. Table 2 shows 27 possible average cycle times of all products corresponding to the different levels of scaling parameters in Table 1.

Table 2: Average cycle time of MIMAC6 with 1.5 target due date flow factor and 95% fab loading, corresponding to different combinations of levels of scaling parameters *P1*, *P2* and *P3*.

Avg. Cycle Time (days)					
P1(L1)P2(L1)P3(L1)	31.0	*P1(L2)P2(L1)P3(L1)*	30.5	*P1(L3)P2(L1)P3(L1)*	30.2
P1(L1)P2(L1)P3(L2)	31.2	*P1(L2)P2(L1)P3(L2)*	30.4	*P1(L3)P2(L1)P3(L2)*	31.0
P1(L1)P2(L1)P3(L3)	30.2	*P1(L2)P2(L1)P3(L3)*	29.9	*P1(L3)P2(L1)P3(L3)*	30.8
P1(L1)P2(L2)P3(L1)	30.8	*P1(L2)P2(L2)P3(L1)*	29.8	*P1(L3)P2(L2)P3(L1)*	30.1
P1(L1)P2(L2)P3(L2)	30.5	*P1(L2)P2(L2)P3(L2)*	29.9	*P1(L3)P2(L2)P3(L2)*	30.3
P1(L1)P2(L2)P3(L3)	29.9	*P1(L2)P2(L2)P3(L3)*	29.2	*P1(L3)P2(L2)P3(L3)*	30.2
P1(L1)P2(L3)P3(L1)	30.4	*P1(L2)P2(L3)P3(L1)*	30.0	*P1(L3)P2(L3)P3(L1)*	31.5
P1(L1)P2(L3)P3(L2)	31.5	*P1(L2)P2(L3)P3(L2)*	30.3	*P1(L3)P2(L3)P3(L2)*	31.2
P1(L1)P2(L3)P3(L3)	29.7	*P1(L2)P2(L3)P3(L3)*	30.1	*P1(L3)P2(L3)P3(L3)*	30.1

From Table 2, we can see that among all the combinations, the best average cycle time performance is achieved by *P1(L2)P2(L2)P3(L3)*, which is Level 2 for *P1*, Level 2 for *P2* and Level 3for *P3* in Table 1. After that, we continue the simulation experiment with due date flow factor ranging from 1.7 to 2.9 in steps of 0.2. To each due date flow factor, we used the same design of experiment like due date flow factor 1.5, with 3 different levels of scaling parameters like Table 1. We found out that different levels should be set corresponding to different due date flow factor to acquire good average cycle time performance. In Table 3, we list the best levels of *P1*, *P2* and *P3* corresponding to different due date flow factors with 95% fab loading.

Secondly, we considered average cycle time, cycle time variance, percent tardy lots and average tardiness for tardy lots as major performance measures which are from the best levels of *P1*, *P2* and *P3* listed in Table 3, and compared the proposed composite rule with MOD and FIFO. Figures 1, 2, 3 and 4 show these four performance measures. As we can see from Figure 1, the composite rule's average cycle time curve has a similar trend like MOD rule. The maximum average cycle time exists at tight due date flow factor 1.5, however, it gets almost 2 days improvement compared to MOD rule. The introduction of LWNQ rule takes effect and brings further WIP balance for the fab, which leads to cycle time reduction.

The average cycle time becomes smaller as due date flow factor changes from tight to loose and reaches its minimum at due date flow factor 2.5 which is differentiated from MOD for minimum average cycle time at due date flow factor 2.3. Besides that, the difference between the composite rule and MOD rule starts at a larger magnitude, then becomes smaller when tight due date is changed to medial due date. The minimum difference is at mediate due date flow factor 2.1, after that, it becomes larger again with loose due date. This tells us that the LWNQ rule has more influence with tight and loose due date than medial due date. With MOD rule, SPT dominates ODD with tight due date and ODD dominate SPT with loose due date. The LWNQ can overcome the WIP imbalance that happens due to only SPT or ODD domination. No matter how due date changes, the composite rule always outperforms FIFO rule.

Table 3: Determination of levels of scaling parameters for different due date flow factors ranging from 1.7 to 2.9 with 95% fab capacity loading

Level Due Date Flow Factor	*P1*	*P2*	*P3*

1.5, 1.7	If ($M>=1$)
	$P1=1+T1$ for $T1<=0.3$
	$P1=2-T1$ for $T1>0.3$
	Else
	$P1=4.5+T1$ for $T1<=0.3$
	$P1=6-2*T1$ for $T1>0.3$
		If ($M>=1$)
		$P2=4.5+T1$ for $T1<=0.3$
		$P2=6-2*T1$ for $T1>0.3$
		Else
		$P2=1+T1$ for $T1<=0.3$
		$P2=2-T1$ for $T1>0.3$
			If ($0<=S<1$)
			$P3=4+S$
			Else If ($S>=1$)
			$P3=-(S+2)$
			Else
			$P3=4+\|S\|$

1.9, 2.1, 2.3	If ($M>=1$)
	$P1=2+T1$ for $T1<=0.5$
	$P1=3-T1$ for $T1>0.5$
	Else
	$P1=4.5+T1$ for $T1<=0.5$
	$P1=6-2*T1$ for $T1>0.5$
		I for $T1>0.5$
		Else
		$P2=2+T1$ for $T1<=0.5$
		$P2=3-T1$ for $T1>0.5$
			If ($0<=S<1$)
			$P3=3+S$
			Else If ($S>=1$)
			$P3=-S$
			Else
			$P3=3+\|S\|$

2.5, 2.7, 2.9	If ($M>=1$)
	$P1=1+T1$ for $T1<=0.7$
	$P1=2-T1$ for $T1>0.7$
	Else
	$P1=5.5+T1$ for $T1<=0.7$
	$P1=7-2*T1$ for $T1>0.7$
		If ($M>=1$)
		$P2=5.5+T1$ for $T1<=0.7$
		$P2=7-2*T1$ for $T1>0.7$
		Else
		$P2=1+T1$ for $T1<=0.7$
		$P2=2-T1$ for $T1>0.7$
			If ($0<=S<1$)
			$P3=5+S$
			Else If ($S>=1$)
			$P3=-(S+2)$
			Else
			$P3=5+\|S\|$

With respect to cycle time variance, it seems due date flow factor 2.3 is a watershed. Figure 2 shows that before 2.3 the composite rule is superior over the MOD rule, and the MOD rule outperforms the composite rule after 2.3. As we mentioned above, SPT plays a more important role than ODD with tight due date in MOD rule, however, SPT does not have a mechanism to reduce cycle time variance. The introduction of LWNQ helps SPT to achieve the better cycle time variance performance. In contrast, ODD is the major influence with loose due dates, and ODD can reduce the lateness relative to due date, thus reducing cycle time variance. The LWNQ can help to achieve WIP balance, however, at the cost of reducing the ODD effect. Therefore, the composite rule is outperformed by the MOD rule with loose due dates.

Concerning the on time delivery performance, if the target due date is too tight, 100% of lots are delayed, vice verse for the loose target due date. Therefore, we only focus on the difference of selected rules with due date flow factor 1.9, 2.1 and 2.3. For other flow factors, the on time delivery percentage is either 100% or 0%. Figure 3 indicates that the composite rule is superior over MOD and FIFO. For flow factor 1.9 and 2.1, the composite rule has less percentage of tardy lots than MOD and FIFO. For flow factor 2.3, the composite rule achieves no tardy lots while FIFO still has around 30% tardy lots. Regarding to the average tardiness for tardy lots, Figure 4 illustrates that the composite rule also achieves a better performance than MOD and FIFO, since the tardiness curve of the composite rule is lower and flatter than MOD and FIFO cases.

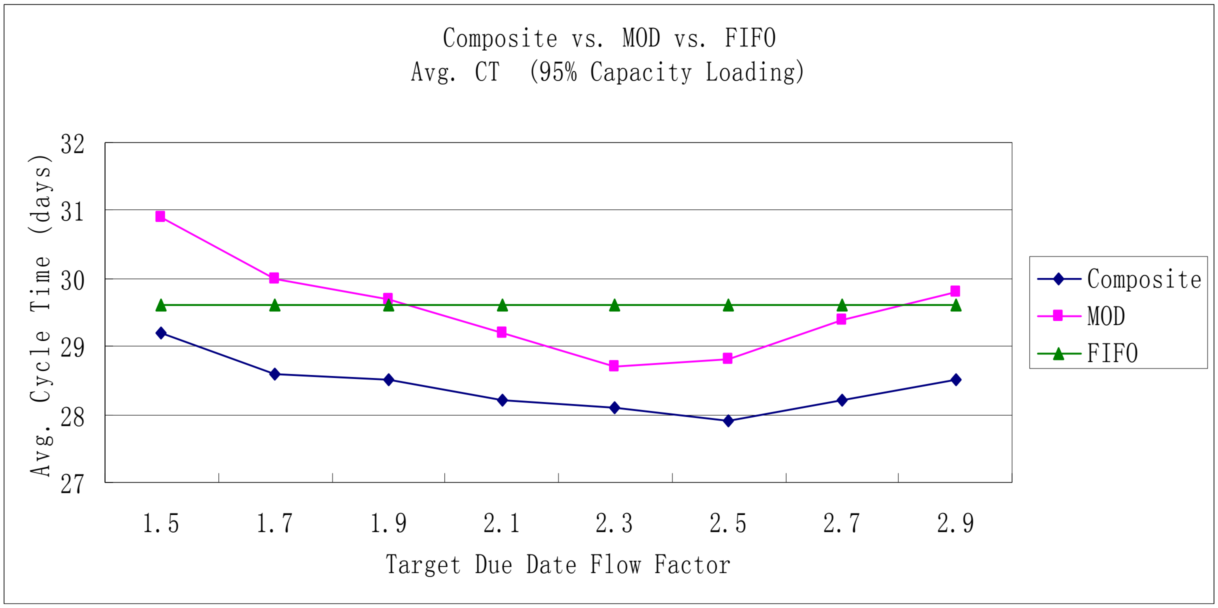

Figure 1: Average cycle time comparison among three rules, under 95% fab loading and with due date flow factor ranging from 1.5 to 2.9 in steps of 0.2.

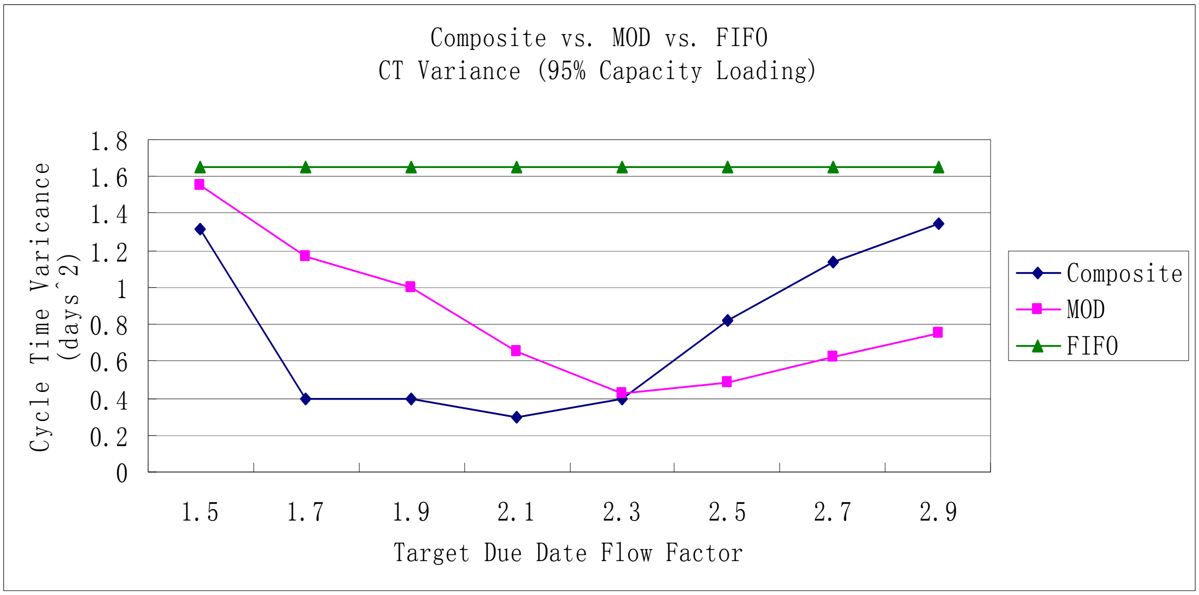

Figure 2: Cycle time variance comparison among three rules, under 95% fab loading and with due date flow factor ranging from 1.5 to 2.9 in steps of 0.2.

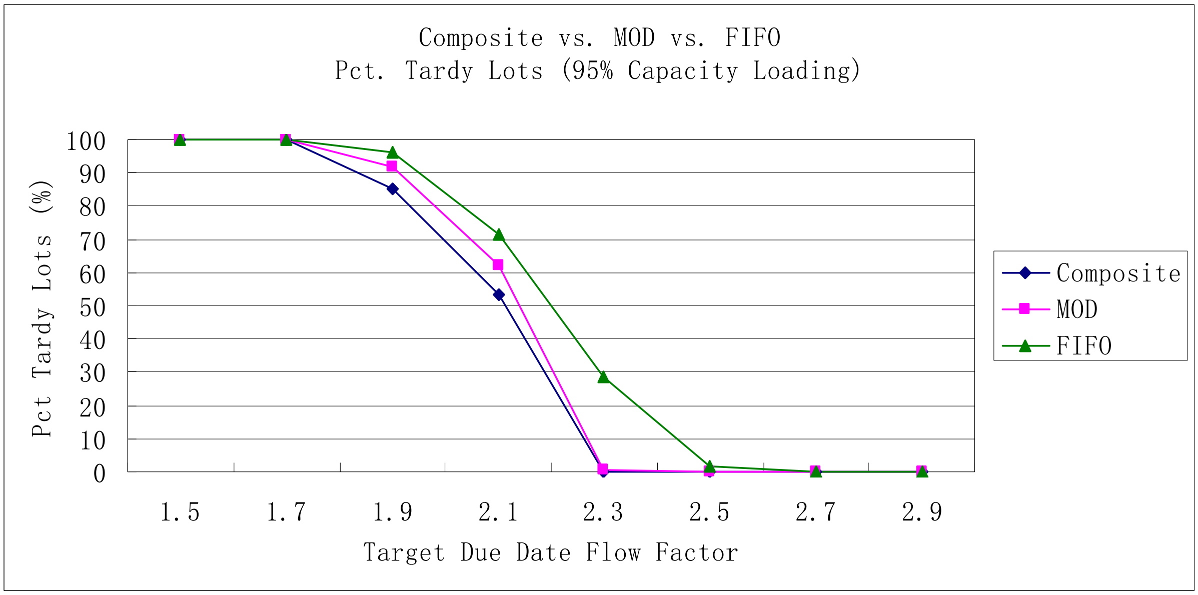

Figure 3: Percent tardy lots comparison among three rules, under 95% fab loading and with due date flow factor ranging from 1.5 to 2.9 in steps of 0.2.

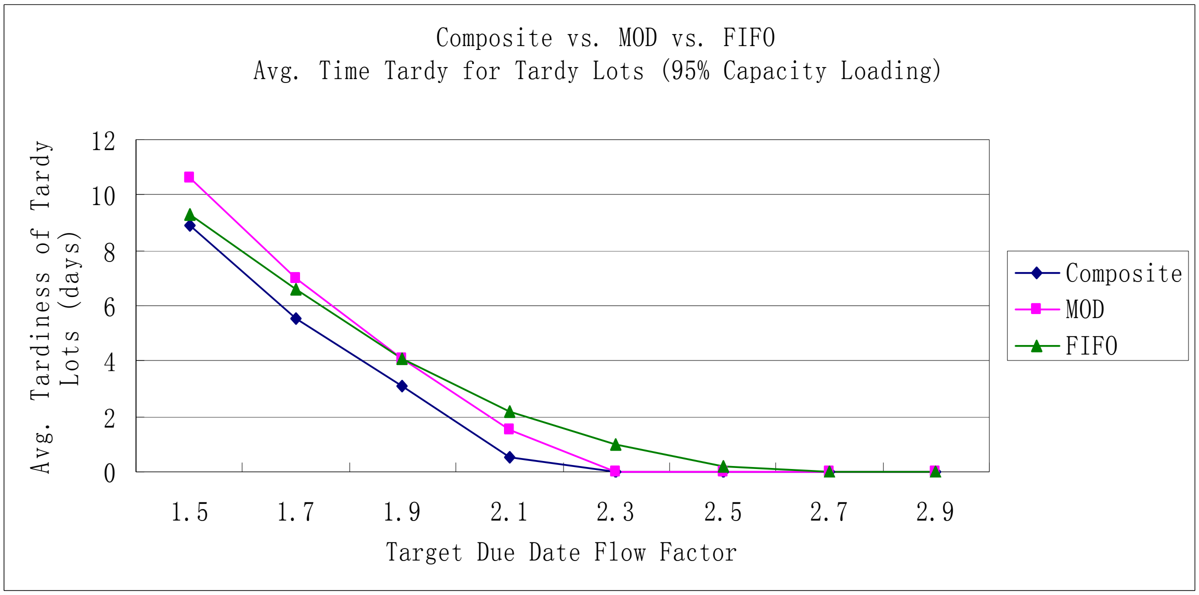

Figure 4: Average tardiness for tardy lots comparison among three rules, under 95% fab loading and with due date flow factor ranging from 1.5 to 2.9 in steps of 0.2.

4 CONCLUSION AND FURTHER WORK

In this study, we proposed a composite rule which combines ODD, SPT and LWNQ rule, to achieve due date control and WIP balance simultaneously. To acquire proper scaling parameters, a design of experiment is used. For each parameter, 3 different levels are determined with factors related to due date and workload information. At first the due date flow factor was set to 1.5. Among 27 possible level combinations in Table 2, the combination of level 2 for parameter 1, level 2 for parameter 2 and level 3 for parameter 3 can achieve best average cycle time performance. By noticing that, we varied the due date flow factor from tight to loose setting and determined the best levels of scaling parameters for each due date flow factor using the same design of experiment. The simulation results demonstrated that the composite rule with appropriate scaling parameters achieves promising results regarding average cycle time, cycle time variance, percent tardy lots and average tardiness for tardy lots performances versus MOD rule.

For the future research, more datasets have to be tested with the composite rule. The difficulty of this proposed composite rule lies in the determination of scaling parameters to figure out the contribution for each single rule. For the design of experiment, more levels should be considered to acquire accurate scaling parameters.

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