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DUE DATE CONTROL IN ORDER-DRIVEN FAB WITH HIGH PRIORITY ORDERS

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ABSTRACT

Presented in this paper is a dispatching rule to achieve the on-time delivery for an order-driven FAB involving high priority orders. We classify orders into two groups; regular orders (RO), high priority orders (HPO). HPO lots have shorter cycle times, tighter target due date and higher margins than RO lots. The proposed rule introduces the concept of reservation for HPO lots, which means the provisional allocation of capacity to meet the on-time delivery of HPO lots. Since the rule considers the due date of HPO lots first, RO lots might be tardy. To minimize the tardiness of RO lots, the proposed rule considers tool utilization as well as on-time delivery of HPO lots. We developed a simulation model based on MIMAC6, and conducted experimentations with MOZART®. The experimentation results show that the proposed dispatching rule can achieve the on-time delivery of HPO lots with the minimum tardiness of RO lots.

1 INTRODUCTION

Semiconductor manufacturers have been engaged in a race against time to produce devices in the most cost effective manner possible (Sarin et al. 2011). According to a report by the semiconductor industry association (SIA), the global sale of semiconductors reached $27.06 billion for the month of October 2013, a 7.2 percent increase from the same month of 2012 when sales were $25.24 billion. The World Semiconductor Trade Statistics (WSTS) forecasted that the industry will reach its highest-ever annual sales total in 2013, and continued growth is projected for 2014 and 2015.

Today's FAB industry can be characterized by strong competition, short product life cycle and increased complexity of products and processes. The production in a wafer fabrication (FAB) is considered as one of the most complex manufacturing processes because of reentrant processing flow, batch processing, sequence dependent setups, unpredictable machine failure (Uzsoy et al. 1992; Johri 1993; Park et al. 2013). It can result in high levels of work-in-process (WIP), long cycle times, and poor due-date performance (Zhou and Rose 2012). To be successful in the globalized competition, it is necessary to improve the production systems, as well as the products (Bahaji and Kuhl. 2008).

The wafer FAB can be seen as a complex job shop. The job shop-scheduling problem is often considered as a sequencing problem to determine the processing order of operations on the machines (Chiang and Fu 2007). There are various approaches to solve job-shop scheduling problems include mathematical programming, branch-and-bound, and dispatching rules. A dispatching rule dynamically determines a

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WIP lot to be processed next once a machine becomes available. Various dispatching rules have been used for shop floor control because of the ease of implementation, quick in reacting to the changes encountered on the shop floor, low computation requirement, and flexibility to incorporate domain knowledge and expertise (Appleton-Day and Shao 1997; Giegandt and Nicholson 1998). Currently, most of the dispatching rules are variants of classical rules like Operation due date (ODD), Earliest due date (EDD), and Critical Ratio (CR), and these rules are often used in an attempt to optimize the on-time delivery (Zhou and Rose 2012; Gibrau and Rose 2012). Although there have been various dispatching rules for on-time delivery, still FABs have great difficulties to achieve the on-time delivery.

For an order-driven FAB, we can classify orders into two groups, which we will refer to as regular order (RO) and high priority order (HPO). While ROs are typically characterized by longer cycle times, looser target due date but lower margins, the HPOs have shorter cycle times, tighter target due date and higher margins. HPO lots are more critical than RO lots with regard to on-time delivery. The presence of HPO lots in production line significantly affects the cycle time and due date control of the RO lots (Ehteshami et al. 1992; Trybula 1993;). However, the dispatching rule considering HPOs has rarely been brought into the focus (Crist and Uzsoy 2011). The objective of this paper is to develop a dispatching rule to achieve on-time delivery of RO lots as well as HPO lots for order-driven FAB.

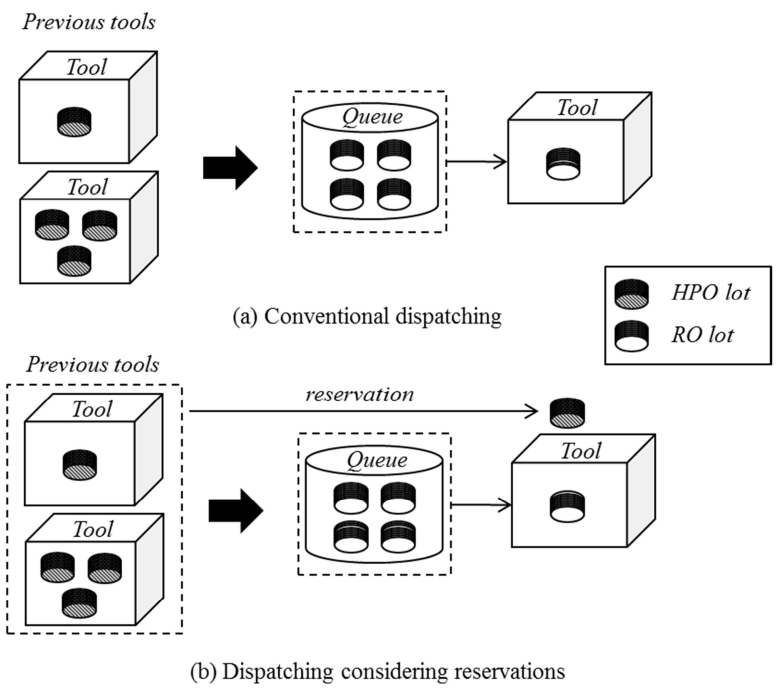

Figure 1: Conventional dispatching and dispatching considering reservations.

As mentioned already, the role of a dispatching rule is to determine a WIP lot to be processed next once a tool becomes available. While conventional dispatching rules (ODD, EDD, CR) only consider lots in the queue of the tool (Figure 1-(a)), the proposed dispatching rule takes into account HPO lots being processed in previous tools as well as the waiting lots in the queue (Figure 1-(b)). The proposed dispatching rule introduces the concept of reservation for HPO lots, which means the provisional allocation of capacity to meet the on-time delivery of HPO lots. Since the dispatching rule considers the due date of HPO lots first, RO lots might be tardy. To minimize the tardiness of RO lots, the proposed dispatching rule takes into account tool utilization as well as on-time delivery of HPO lots.

The simulation experiments are carried out with commercial software MOZART® developed by the VMS solutions (Ko et al. 2013). The overall structure of the paper is as follows. Section 2 addresses the approach of this paper for the proposed dispatching rule, and Section 3 describes the experimental design and analyzes experimental results. Finally, concluding remarks are given in Section 4.

2 APPRAOCH TO ACHIEVE ON-TIME DELIVERY

This section addresses a dispatching rule considering HPO lots. For the problem, we may think of a typical method called a Simple HPO rule, which forces HPO lot to be processed next. This simple rule makes decisions only by considering WIP lots of the tool, and does not have the concept of reservation, the provisional allocation of capacity. Because of the reason, the Simple HPO rule may not achieve the intended level of on-time delivery of HPO lots.

To cope with the problem, we develop a dispatching rule with the concept of reservation. As shown in Figure 1-(b), the proposed dispatching rule considers not only WIP lot of the current tool (step) but also HPO lots of previous tools (steps). A tool may reserve only one HPO lot at a time, and it cannot reserve any other HPO lots until it finishes the processing of the reserved HPO lot. Because of the reason, some HPO lots may wait in the queue without reservations together with RO lots. The proposed dispatching rule gives three different priorities, as follows.

- First group (Priority 1): Reserved HPO lot for the tool.
- Second group (Priority 2): If there is no reserved HPO lot, then we apply ODD dispatching rule for HPO lots without reservations. In the case of ties, FIFO is applied.
- Third group (Priority 3): If there is no HPO lot at all, we apply ODD dispatching rule for RO lots. In the case of ties, FIFO is applied.

For the performance of the proposed dispatching rule, it is very important to develop a reasonable reservation policy. The proposed dispatching rule tries to minimize the waiting time of HPO lots. Whenever a tool becomes free at time *t1*, it searches proper candidates for reservation among HPO lots of previous tools. If there are multiple candidates, it chooses the first expected-to-arrive HPO lot. Let's assume that the chosen HPO lot arrives at time *t2* (>*t1*). If there are no RO lots, which can be finished before *t2*, then the tool reserves the HPO lot. Once the tool is reserved, then it has to wait until the arrival of the chosen HPO lot. If there exist a RO lot, which can be finished before *t2*, then the tool does not reserve the HPO lot to prevent the capacity loss. In the case of no reservation of a HPO lot, then it applies the classical ODD rue for WIP lots of the tool. For the formal explanation of the proposed reservation policy, we define several terms as follows.

- *t1* : current time
- PT(i, k) : Processing time of lot i at step k.
- FT(i, k) : Finish time of lot i at step k.
- TT (k-1, k) : Transfer time to move from step k-1 to step k.
- AT(i, k) : arrival time of lot i at step k.

Based on the definitions, we can derive following equations.

- *FT(i, k) = t1 + remaining PT(i, k).*
- *AT(i, k) = FT(i, k-1) + TT (k-1, k).*

Let's assume that a tool belonging to step k becomes available at time *t1*. At this situation, the reservation algorithm can be described as follows.

- **Reservation Algorithm of a tool considering HPO lots.**

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Step 1) H-lot = Find the first arriving HPO lot to step k among HPO lots belonging to the
                previous step k-1 ;
Step 2) If (H-lot != NULL)
             t2 = AT (H-lot, k) ;
        Else
             t2 = ∞;
Step 3) R-lot = Apply ODD rule for WIP lots of the tool;
Step 4) t3 = FT (R-lot, k) ;
Step 5) If (t2 < t3)
             Reserve H-lot, and wait until the arrival of the H-lot;
        Else
             Do not Reserve the H-lot & Start the processing of R-lot ;
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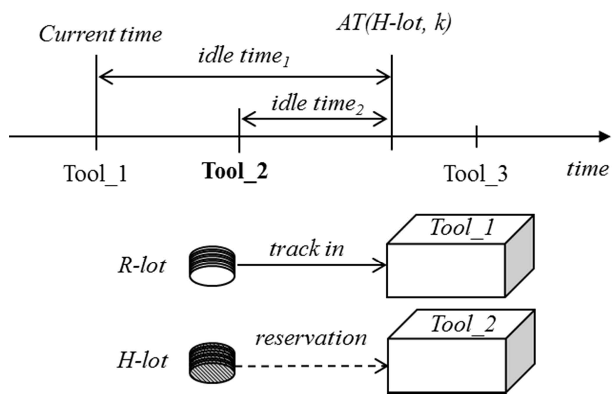

Figure 2: Reservation assignment among homogeneous tools.

The described reservation algorithm works for a tool, which becomes available. Once an H-lot is reserved by a tool, the tool must wait until the H-lot enters in the queue of the tool. This attribute could decrease the utilization of the tool, which is also an important performance measure of FABs. Most of cases, a tool group consists of multiple homogeneous tools. Considering the existence homogeneous tools, we may think of a better assignment policy of reservations. In other words, we may try to find the best tool for the reservation in the tool group, which can minimize the capacity loss (idle time). Figure 2 shows a tool group consisting of three homogeneous tools (Tool_1, Too_2, and Tool_3). Tool_1 becomes free at t1, and finds a reservation candidate (H-lot) according to the reservation algorithm. Since the arrival time of the H-lot is t2, Tool_1 has to wait for the time period of t2-t1. If we assign the H-lot to Tool_2, we can save the idle time because Tool_2 becomes free at t3 (t2-t3 < t2-t1). On the contrary, it is not desirable to assign the H-lot to Tool_3, because Tool_3 becomes free after the arrival of the H-lot. In this way, we can achieve better on-time delivery of HPO lots with the minimum capacity loss.

3 SIMULATION RESULT AND PERFORMANCE ANALYSIS

To conduct the simulation experimentation, we employ the MOZART® engine developed by VMS solutions (Ko et al. 2013). Based on master plan (MP) and current WIP, MOZART® generates loading schedule of each tool and production plan using dispatching rules. There are three master data for a simulation: bill of process (BOP) model, resource model, and dispatching model. BOP model is a network, which combines BOM (bill of material) and process routing, and it contains step sequence, loadable resource list and processing time for each step, and transfer time. Resource model includes handling units, processing types, and defect treatment policies. Each resource has dispatching rule and tack/processing time. MOZART® supports implementation of various dispatching rules: (1) fab-wide rules versus machine-specific rules; (2) single rules versus composite rules.

Multiple experimentations have been performed for three different ratios of HPO lots, 10%, 20%, and 30%. ODD is calculated in the following way : *ODD = Due Date – Remaining RPT * Flow factor* where RPT is the raw processing time of the lot, and flow factor (FF) is defined as the target cycle times divided by the RPT. Simple HPO rule forces HPO lot to be processed next. The objective of this rule is to achieve the on-time delivery of HPO lots without reservations. This rule makes decision only by considering lots in the queue of a tool.

Table 1: Configuration of simulation model used in this study.

Modeling aspect	**Value**
Number of products (processes)	9
Number of tool groups	104
Number of tools	230
Wafers in a lot	24
Lots released per year	2706
Number of tools per tool group	2-7
Rework modeled ?	No
Yield loss (scrap) modeled ?	No
Raw processing time range (hours)	211-334
Number of processing steps range	234-355
Total number of processing steps	2541
Batching policy	Minimum batch size
Sequence dependent setup	Yes

For the experimentation of the proposed dispatching rule, we constructed by using a small wafer FAB dataset MIMAC6 from Measurement and Improvement of Manufacturing Capacities (MIMAC). It is necessary to refer to the MIMAC Final Report for the explanation details (Fowler and Robinson 1995). We construct the FAB model based on the MIMAC6, and some of the features are described in table 1.

The total time period of simulation is nine months. Since the first six months are for the worm-up, the time period is not taken into account for the results. As major performance measures, percent tardy lots, average tardiness of tardy lots, and average cycle time are determined. For RO lots, three different flow factors (2.6, 2.4, 2.8) are considered. In the case of HPO-lots, we give a very tight flow factor (1.15) because HPO lots usually require tighter target due dates.

The seven experimental results are presented in Tables 2 & 3. The first experimentation of Table 2 is performed for 10 % of HPO lots and 2.6 flow factor of RO lots. The simple HPO rule gives slightly better on-time delivery of HPO lots (21.54% of tardy) compared to the ODD rule (29.03% of tardy). Although the simple HPO rule is better than the classical ODD rule, the tardy percent of HPO lots is still very high. This is because the simple HPO rule makes decisions only for WIP lots without reservations of HPO lots. Thus, both of rules are not acceptable in terms of the on-time delivery of HPO lots.

The proposed rule employs the concept of reservations, and gives zero tardy percent of HPO lots for all of the seven experimentations. In the case of RO lots, the tardy percent (6.32%) is slightly higher than other two rules (1.04%, 1.91%), but still acceptable.

Table 2: Four performance measures of each dispatching rules.

Flow factor : 2.6(RO) / 1.15(HPO), Ratio of HPO : 10%							
	Tardy lots (%)		Tardiness (day)		Cycle time (day)		Tool utilization (%)
	RO	HPO	RO	HPO	RO	HPO	
ODD	1.04	29.03	0.27	0.25	24.89	11.82	97.55
Simple HPO	1.91	21.54	0.33	0.14	24.9	11.82	97.55
Proposed rule	6.32	0	0.38	0	25.23	11.13	96.92
Flow factor : 2.6(RO) / 1.15(HPO), Ratio of HPO : 20%							
	Tardy lots (%)		Tardiness (day)		Cycle time (day)		Tool utilization (%)
	RO	HPO	RO	HPO	RO	HPO	
ODD	0.98	14.17	0.18	0.32	24.57	11.69	98
Simple HPO	1.95	5.34	0.3	0.07	24.59	11.66	98
Proposed rule	9.72	0	0.66	0	25.27	11.14	96.82
Flow factor : 2.6(RO) / 1.15(HPO), Ratio of HPO : 30%							
	Tardy lots (%)		Tardiness (day)		Cycle time (day)		Tool utilization (%)
	RO	HPO	RO	HPO	RO	HPO	
ODD	0	26.67	0	0.11	22.64	11.79	98.1
Simple HPO	1.16	25.13	0.29	0.07	22.62	11.78	98.1
Proposed rule	6.13	0	0.91	0	23.87	11.23	96.32

Table 3: Four performance measures of each dispatching rule with different flow factors

Flow factor : 2.4(RO) / 1.15(HPO), Ratio of HPO : 10%							
	Tardy lots (%)		Tardiness (day)		Cycle time (day)		Tool utilization (%)
	RO	HPO	RO	HPO	RO	HPO	
ODD	30.22	80.33	0.76	0.89	24.99	12.6	97.47
Simple HPO	39.13	25.76	0.72	0.15	25.1	11.81	97.47
Proposed rule	48.94	0	1.07	0	25.46	11.16	96.72
Flow factor : 2.4(RO) / 1.15(HPO), Ratio of HPO : 30%							
	Tardy lots (%)		Tardiness (day)		Cycle time (day)		Tool utilization (%)
	RO	HPO	RO	HPO	RO	HPO	
ODD	8.56	30.89	0.68	0.57	23.69	11.93	97.88
Simple HPO	10.5	18.09	0.9	0.09	23.75	11.78	97.83
Proposed rule	35.57	0	1.34	0	24.93	11.23	96.23
Flow factor : 2.8(RO) / 1.15(HPO), Ratio of HPO : 10%							
	Tardy lots (%)		Tardiness (day)		Cycle time (day)		Tool utilization (%)
	RO	HPO	RO	HPO	RO	HPO	
ODD	0	7.69	0	0.11	25	11.71	97.83
Simple HPO	0	7.69	0	0.11	25	11.71	97.83
Proposed rule	0	0	0	0	25.25	11.13	97.25
Flow factor : 2.8(RO) / 1.15(HPO), Ratio of HPO : 30%							
	Tardy lots (%)		Tardiness (day)		Cycle time (day)		Tool utilization (%)
	RO	HPO	RO	HPO	RO	HPO	
ODD	0	20.71	0	0.11	22.15	11.77	98.22
Simple HPO	0	20.71	0	0.11	22.15	11.77	98.22
Proposed rule	1.19	0	0.14	0	23.35	11.23	96.65

4 SUMMARY

The production in a wafer FAB is one of the most complex manufacturing processes. To be successful in the competition, it is very important to improve the production system. The FAB scheduling problem is often considered as a dispatching problem to determine the processing order of operations on the tools. Currently, most of the dispatching rules are variants of classical rules like ODD, EDD, and CR, and these rules is often used to optimize the on-time delivery.

For an order-driven FAB, we can classify orders into two groups : RO lots and HPO lots. HPOs are more critical than ROs regarding with on-time delivery. Although, the presence of HPO lots in production line significantly affects the cycle time and due date control of the RO lots, the dispatching rule considering HPOs has rarely been brought into the focus.

We propose a dispatching rule considering reservations that means the provisional allocation of capacity to achieve the on-time delivery of HPO lots. While HPO lots can be ensured capacity of tools, RO lots are sacrified from special handling for HPO lots. According to the objective of this paper, the proposed rule considers on-time delivery of RO lots as well as HPO lots. To minimize a capacity loss for RO lots, HPO lots can be reserved by other tools belonging to same tool group.

For the simulation using the proposed dispatching rule, we used a commercial software MOZART® developed by VMS solutions. The simulation results show that the proposed dispatching rule is superior over ODD, Simple HPO with regard to the on-time delivery and the average cycle time of HPO lots.

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