The Preemptive Stocker Dispatching Rule of Automatic Material Handling System in 300 mm Semiconductor Manufacturing Factories

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Abstract. The integrated circuit (IC) manufacturing industry is one of the biggest output industries in this century. The 300mm wafer fabs is the major fab size of this industry. The automatic material handling system (AMHS) has become one of the most concerned issues among semiconductor manufacturers. The major lot delivery of 300mm fabs is used overhead hoist transport (OHT). The traffic jams are happened frequently due to the wide variety of products and big amount of OHTs moving in the fabs. The purpose of this study is to enhance the delivery performance of automatic material handling and reduce the delay and waiting time of product transportation for both hot lots and normal lots. Therefore, this study proposes an effective OHT dispatching rule: preemptive stocker dispatching (PSD). Simulation experiments are conducted and one of the best differentiated preemptive rule, differentiated preemptive dispatching (DPD), is used for comparison. Compared with DPD, The results indicated that PSD rule can reduce average variable delivery time of normal lots by 13.15%, decreasing average variable delivery time of hot lots by 17.67%. Thus, the PSD rule can effectively reduce the delivery time and enhance productivity in 300 mm wafer fabs.

Keywords – AMHS, 300 mm Semiconductor manufacturing, OHT, Stocker

1. Introduction

The integrated circuit (IC) industry is one of the big global industries in twenty first century. Continuous technology innovation of IC industry is the growth momentum of electronics industry and facilitates improvement in product functions. Semiconductor industry is capital-intensive and highly competitive. To sustain IC companies’ competitive advantage, it is very important to maximize the output under the resource limitations and enhance the productivity \cite{1}.

The semiconductor industry is at a significant turning point. To maintain industry profitability and growth, new ideas for cost effective manufacturing must be aggressively pursued that go beyond simply enlarging the scale of production to achieve efficiency. As the size of wafer increased from 200 mm to 300 mm, weight of wafer grew from 4 kilograms to 10 kilograms. To prevent the occupational accident and increase yield rate and cleanness, automated material handling system (AMHS) has recently become the indispensable equipment in wafer fabs. The major lot delivery of 300mm fabs is used overhead hoist transport (OHT), which is one of the major vehicles of AMHS. Factory

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automation has translated into unmanned plant; therefore, machine operation is fully automated. However, frequently blocking of OHT is happened in intrabay. The moving speed of OHT is very fast around 1 meter per second. The OHT is always moving in the same direction, excluding it is doing the hoisting work. When OHT executes a hoisting work, the other OHTs behind the hoisting one will be blocked. This issue will have great delay for the delivery time of lots. AMHS will directly affect the transportation efficiency of the lots delivery [1].

In semiconductor fab, some products are very important, and they demand short cycle time and on time delivery. These products of high priority are called hot lots. Hot lots have high preemptive against other lots. Due to the increased size and weight of 300 mm wafers, the factories faces more challenges. Pilot production are normally arranged to be hot lots. They are more frequently emerging due to the increased variety of new products with small production volume. The 300 mm automatic transport system should differentiate its services to different priorities to match with frequent process changes and fine tune of the small production volumes of products. This paper objective is to provide the transport services to minimize the delivery delay of hot lots with minimum impacts for normal lots in 300 mm OHT environment [1].

The dispatching rules are very helpful in AMHS environment. proposed A routing algorithm was presented to facilitate both routing and control of the vehicles. The most commonly rules for zone blocking, loading/unloading and traffic control and communications was outlined [2]. Liao and Wang[1] developed a rule for the material handling of high priority products called differentiated preemptive dispatching (DPD) policy to provide differentiated priority handling services in a 300 mm fab. Its concept was a lot with higher priority should have its privilege of transportation against those with lower priority.

Some researchers have studied various approaches to improve delivery time performance. Lee et al. [3] implemented efficient scheduling and dispatching policies to gain competitiveness for modern semiconductor manufacturing systems. Fowler et al. [4] remarked that the presence of bottlenecks implies that careful attention and control will not directly have big effect on system performance. Koo et al. [5] described that a system’s throughput was usually determined by bottleneck resources, which was the fundamental principle of the theory of constraints (TOC). This paper presents a vehicle dispatching policy to improve bottleneck resource.

However, none of the researchers have ever put attention on the stocker arrangement of 300mm OHT transportation. Therefore, this research proposes a heuristic OHT dispatching rule, preemptive stocker dispatching (PSD) to minimize the transport delay of lots a for lots transport services.

The remainder of this paper is organized as follows. The OHT dispatching rule is proposed in Section 2. rule. Section 3 conducts the experiment designs based on generic data from 300 mm fab of international SEMATECH. Section 4 demonstrates the experiment results and analysis. Finally, conclusions and future research directions are made in Section 5.

2. Preemptive Stocker Dispatching Rule

This study defines a transport job as a macro of transfer commands. The OHT dispatching is an assignment of a transport job to an empty OHT. The OHT variable delivery time is defined as the time to complete a transport job. The dispatched OHT is reserved to the job when it is dispatched, and becomes empty again after completing this job. The objective of OHT dispatching is to minimize OHT delivery time.

The non-reserved OHT will keep moving along the same direction with a specific distance to its front OHT, and all OHTs are equal distribution in each bay. When a set of transport jobs are ready for and waiting to be transferred by OHTs. An empty OHT (reserved OHT or non-reserved OHT) is dispatched to the highest priority job and the transportation of the OHT is preemptive. Once an empty OHT is dispatched to the highest priority job, any other ongoing transport operations, which may block this OHT, will become delay until this highest priority job is completed. If no such highest priority job exists, a non-reserved OHT follows the rule of first-meet and first-serve for normal transport jobs. But if there are several non-reserved OHTs move together, and a lot job is issued before
them, the job will be dispatched to the last OHT for avoiding those OHTs blocked by the first OHT. Figure 1 shows the flow of PSD rule.

**Figure 1.** The PSD rule

The PSD algorithm is explained in detail as below:

1. **The overall rule**
   - **Step1.** OHTs are assigned to each bay evenly, and each intrabay has the same quantity of OHTs.
   - **Step2.** When the quantity of OHTs assigned to a certain intrabay is less than the specified number, the empty OHT’s of the interbay will go to the intrabay when approaching it. When the quantity of OHTs assigned to a certain intrabay is more than the specified number, the surplus of empty OHT’s will go to the interbay automatically.
   - **Step3.** The non-reserved empty OHT always follows the “first-meet and first-serve” on transport jobs. Carry the lot to the intrabay of the next process, selecting an unoccupied machine. If all machines are occupied, then carry the lot to the nearest stocker, if the nearest stocker is full, then go to the second nearest, and so forth.
   - **Step4.** When any machine of an intrabay is available, if there is any waiting lot at the stocker, the stocker will issue a signal, then the reserved empty OHT will carry the lot from stocker to
the available machines according to the rule of “first meet, first serve”.

Step 5. There are several non-reserved empty OHTs in front of a reserved empty OHT. When a lot job is issued, it is reserved to the last non-reserved OHT, not follows “first-meet and first-serve”.

Step 6. If a hot lot job is issued, follow the hot lot rule.

(2) The hot lot rule

Step 1. When an reserved empty OHT is going to carry the normal lot, as long as a hot lot gives a signal, this reserved empty OHT will abandon the original assignment and change to carry this hot lot.

Step 2. The AMHS controller, which is named as material control system (MCS), checks the location of all non-reserved empty OHTs. Reserve the nearest empty OHT to execute this job.

Step 3. Even an empty OHT is reserved for a hot lot, if another empty OHT occurs and is closer to this hot lot than the original reserved OHT, the MCS changes the reservation to the nearest OHT.

Step 4. If there are no any empty OHT, the MCS waits until the first empty OHT appear. Then MCS reserves this only empty OHT to execute that job.

Step 5. If more than one hot lot jobs are issued, an empty OHT follows the “first hot lot meet and first hot lot serve”.

Step 6. If an reserved empty OHT or an OHT carrying a hot lot are approaching any OHT within a distance $D_1$, loading/unloading operations are prohibited to this front OHT for any normal lot. $D_1$ is designed to prevent any blocking to the OHT with a hot lot by other OHTs. $D_1$ is equal to the average moving speed multiplied by the hoisting time of lots.

3. Simulation experiments

The AMHS is a quite complex system in the semiconductor fab. It is too complex to complete the real simulation situation. Therefore, This research simplify systems under the International SEMATECH Reports [6][7] for 300mm factory. The generic models are enough for the performance evaluation of the different handling rules. This simulation models are implemented with the discrete-event simulation package - Flexsim from Canyon park technology center. Flexsim is an object-oriented simulation tool with analysis modules that can help engineers and planners make decisions in the design and operation of a system.

Besides the PSD rule, this research also choose differentiated preemptive dispatching (DPD) rule for the performance comparison. The DPD rule utilizes the straightforward idea of first serve with the high priority. Now it has been suggested as a good rule to different preemptive product in OHT applications [1].

Observing the real environment of the OHT system, this research consider three domination control variables: bay loading ratio, hot lots ratio, and the quantity of OHTs. As the number of OHTs increase, system performance will usually be changed due to the increased resources. Therefore, this research considers for configurations of the three kinds OHT numbers, 15, 18 and 21. The increasing hot lots ratio will impose long time delays on the normal lots drastically. Three distributions of hot lots, 2%, 6% and 10% are designed for the tests. The hot lots ratio is the average number of hot lots divided by the average number of total lots in whole factory. Moreover, the heavy bay loadings are used to highlight the effect of the rules in resource limitation. The bay loading is defined as the average quantity of hourly lot input divided by the maximum quantity of hourly lot output of the bottleneck bay. Three loading ratios, 90, 95 and 100% of the design specification, are used in the simulation. The total number of simulation experiments performed is $3 \times 3 \times 3 \times 3 = 81$. The simulation horizon is set to 14 days long with a one day pre-run for each experiment.

Moreover, the performance index are defined also following by Liao and Wang's literature [1]. The average lot delivery time = the theoretical moving time + loading and unloading time + product
waiting time. The theoretical moving time and loading and unloading time cannot be changed. But waiting time is waste and can be reduced. A good rule can reduce the waiting time. Therefore, a good method can shrink the product delivery time. So, this research take “variable delivery time” as the main index of performance to demonstrate the efficient result.

4. Simulation results and analysis

All simulation results of average variable time for PSD and DPD are demonstrated on Table 1.

| System configuration | Average lots variable delivery time (in seconds) |
|---------------------|-----------------------------------------------|
|                     | Normal lots | Hot lots | Normal lots | Hot lots |
| # of HOTs | Bay loading | Hot lot ratio | PSD | | | DPD | |
| 15 | 90% | 2% | 682.705 | 464.151 | 810.165 | 582.736 |
| 15 | 95% | 2% | 737.646 | 511.872 | 830.901 | 577.993 |
| 15 | 100% | 2% | 800.646 | 529.769 | 865.579 | 596.828 |
| 15 | 90% | 6% | 728.800 | 448.139 | 846.681 | 580.723 |
| 15 | 95% | 6% | 779.033 | 455.547 | 930.354 | 568.331 |
| 15 | 100% | 6% | 885.845 | 486.732 | 971.958 | 571.988 |
| 15 | 90% | 10% | 789.306 | 523.394 | 890.923 | 611.834 |
| 15 | 95% | 10% | 871.854 | 534.448 | 984.921 | 612.430 |
| 15 | 100% | 10% | 910.069 | 537.782 | 997.958 | 623.750 |
| Average of 15 vehicles | | | 798.434 | 499.093 | 903.271 | 591.846 |
| 18 | 90% | 2% | 647.169 | 458.101 | 782.583 | 544.208 |
| 18 | 95% | 2% | 723.671 | 464.937 | 841.151 | 567.685 |
| 18 | 100% | 2% | 771.190 | 487.515 | 844.616 | 580.333 |
| 18 | 90% | 6% | 715.300 | 438.756 | 827.428 | 514.394 |
| 18 | 95% | 6% | 753.622 | 463.517 | 900.046 | 560.138 |
| 18 | 100% | 6% | 834.093 | 479.023 | 958.124 | 573.280 |
| 18 | 90% | 10% | 751.102 | 473.768 | 870.328 | 583.065 |
| 18 | 95% | 10% | 828.670 | 500.144 | 965.528 | 605.588 |
| 18 | 100% | 10% | 889.746 | 516.246 | 971.472 | 607.425 |
| Average of 18 vehicles | | | 768.285 | 475.779 | 884.586 | 570.680 |
| 21 | 90% | 2% | 621.922 | 405.343 | 737.727 | 528.472 |
| 21 | 95% | 2% | 702.836 | 416.705 | 813.343 | 515.513 |
| 21 | 100% | 2% | 714.409 | 437.624 | 816.353 | 569.101 |
| 21 | 90% | 6% | 681.807 | 402.135 | 794.888 | 503.144 |
| 21 | 95% | 6% | 731.446 | 424.136 | 844.877 | 553.001 |
| 21 | 100% | 6% | 797.992 | 463.812 | 939.593 | 578.811 |
| 21 | 90% | 10% | 697.103 | 455.648 | 841.160 | 566.363 |
| 21 | 95% | 10% | 759.838 | 470.103 | 943.241 | 594.096 |
| 21 | 100% | 10% | 853.492 | 486.995 | 968.752 | 598.147 |
| Average of 21 vehicles | | | 728.983 | 440.278 | 855.548 | 556.294 |
| Total average | | | 765.234 | 471.716 | 881.135 | 572.940 |

The experimental results show that the average variable delivery time of PSD is faster than DPD for both hot lots and normal lots in all scenarios. In the 15 OHTs portion, the time for normal lot of PSD is fast compared to that for the DPD (from average 903.271 seconds to average 798.434 seconds), and the time for hot lot of PSD is shorter than DPD (from 591.846 seconds to 499.093 seconds). Overall, the PSD reduces the average delivery time of normal lots by 13.15% (from 881.135 seconds to 765.234 seconds) and the hot lots reduces the average variable delivery time is 17.67%
(from 572.940 seconds to 471.716 seconds) in average of all scenarios. This research finds that the PSD performs significantly well as compared to the DPD. In order to compare these two rules, this study displays the tendency charts of average lots variable delivery time in different configurations. Figure 3 demonstrates the results comparison in different configurations. It demonstrates the average results of 3 kinds of system loading ratio, 3 different hot lot ratio, and 3 different OHT number. When increasing loading or hot lot ratio, all curves trend upward, and when increasing the OHT number, each curve trends downward. Obviously, the Figure 2 manifests that PSD is better than DPD.

![Figure 2. Simulation average results in different configurations](image)

Statistical testing is conducted to distinguish the major difference of these two rules. Error! Reference source not found. and Error! Reference source not found. shows rule comparison between the DPD and PSD rules for normal lots and hot lots. Compare with DPD and PSD rules by statistics testing, the average transport time of normal lots and hot lots do have significant difference. It depicts the results of testing with pair data for the average variable delivery time. Error! Reference source not found. shows the testing with pair data of variable delivery time for normal lots. The t-value is 40.74, and the p-value is 0. There are significantly differences between DPD and PSD rules. This means the normal lots variable time can be significantly reduced by PSD. Error! Reference source not found. depicts the results of testing with pair data of variable delivery time for hot lots. Its t-value is 48.78, and the p-value is 0, which means that these two rules are also significantly different. This means the PSD rule still performs better than the DPD rule on hot lot delivery. According to the results above, the PSD is performs better significantly less than the DPD rule in minimizing variable delivery times for both normal and hot lots.

Above the synthesis tests of the result, proposed PSD rule to be able effectively to carry out the lots transportation. It reduces the possible detention of transportation. Simultaneously tests discovered when the OHT resource is sufficient, the PSD rule is effective. However, in real situation of a semiconductor fab, the OHT quantity mostly is sufficient. The PSD rule is a better dispatching rule for shortening the lot variable time for both lots and normal lots when sufficient OHT vehicles are present.
### Table 2. Rule comparison between the DPD and PSD rules for normal lots

| Rule     | N  | Mean     | STDEV  | SE Mean | The Lower 95% Confidence Interval | DF | t-value | p-value |
|----------|----|----------|--------|---------|----------------------------------|----|---------|---------|
| DPD      | 81 | 881.135  | 71.431 | 9.793   |                                  |    |         |         |
| PSD      | 81 | 765.234  | 74.819 | 8.313   |                                  |    |         |         |
| DPD-PSD  | 81 | 115.902  | 25.602 | 2.845   | 110.241                          | 80 | 40.74   | 0.000   |

### Table 3. Rule comparison between the DPD and PSD rules for hot lots

| Rule     | N  | Mean     | STDEV  | SE Mean | The Lower 95% Confidence Interval | DF | t-value | p-value |
|----------|----|----------|--------|---------|----------------------------------|----|---------|---------|
| DPD      | 81 | 572.940  | 30.631 | 3.403   |                                  |    |         |         |
| PSD      | 81 | 471.716  | 37.652 | 4.184   |                                  |    |         |         |
| DPD-PSD  | 81 | 101.223  | 18.674 | 2.075   | 97.094                           | 80 | 48.78   | 0.000   |

5. Conclusions

This paper proposes an effective OHT dispatching rule to transportation services for lots under 300 mm wafer manufacturing. The objective is to minimize the transportation delay of lots and reduce job waiting times. The results of simulation experiments demonstrate that the PSD dominates the DPD in lots delivery performances. Compared with DPD, the PSD rule can reduce the average lot variable delivery time of normal lots by 13.15% (from 881.135 seconds to 765.234 seconds) and 17.67% (from 572.940 seconds to 471.716 seconds) for lot lots. From statistical testing, there are significantly differences between the PSD and DPD rules. Therefore, the PSD is better than the DPD. When increasing hot lot ratio or bay loading, the results will get upward trend for normal lots and hot lots. When increasing the OHT number, the trend of results will decline. The result shows the PSD has the shorter variable time of normal lots and hot lots in each environment. The proposed PSD rule is very useful to the shop floor control in 300mm AMHS factory.

For the future researches, it can conform to transmit demand for all levels of products and use PSD rule as the basis of 450 mm wafer fab in transport policy. Moreover, high products mix or segmented dual-track bidirectional loop (SDBL) could be also be consider. Expand simulation model to a full-scale factory environment could be also a good application.

References

[1] Liao D Y and Wang C N 2006 Differentiated preemptive dispatching for automatic materials handling services in 300mm semiconductor foundry *International Journal of Advanced Manufacturing Technology.* 29 (9) 890-896

[2] Vosniakos G C and Mamalis A G 1990 Automated guided vehicle system design for FMS applications *International Journal of Machine Tools and Manufacture.* 30(1) 85-97

[3] Lee Y F, Jiang Z B and Liu H R 2009 Multiple-objective scheduling and real-time dispatching for the semiconductor manufacturing system *Computers and Operations Research.* 36(3) 866-884

[4] Fowler J W, Hogg G L and Mason S J 2002 Workload control in the semiconductor industry *Production Planning and Control.* 13(7) 568-578
[5] Koo P H, Jang J and Shu J 2005 Vehicle dispatching for highly loaded semiconductor production considering bottleneck machines firsts International Journal of Flexible Manufacturing Systems. 17(1) 23-38

[6] Quinn T and Bass E 1999 300 mm factory layout and material handling modelling: phase I report Austin, TX, International SEMATECH

[7] Campbell E and Ammenheuser J 1999 300 mm factory layout and material handling modelling: phase II report Austin, TX, International SEMATECH