Proceedings of the 2008 Winter Simulation Conference
S. J. Mason, R. R. Hill, L. Mönch, O. Rose, T. Jefferson, J. W. Fowler eds.

STUDY OF OPTIMAL LOAD LOCK DEDICATION FOR CLUSTER TOOLS

Julie Christopher

IBM Microelectronics
2070 Route 52
Hopewell Junction, NY 12533, USA

ABSTRACT

Cluster or chamber tools are often used in the semiconductor industry. In a research environment, moving to smaller device dimensions requires experimentation with new chamber types and materials to overcome challenges with Moore's Law. To make the most of expensive mainframes and clean room floor space multiple chamber types can be placed on one mainframe. Although this type of configuration can reduce cost while evaluating new complex processes, the efficiency of the tool as a whole can be drastically reduced. A major bottleneck within tools configured with multiple process chambers can be the load locks. These load locks are the single wafer entry point into the vacuum chamber. This paper will show the effect of load lock dedication on a sample multi-process chamber tool.

1 INTRODUCTION

This paper explores a simulation experiment on load lock dedication for a chamber tool in a 300mm semiconductor fab. The experiment is performed on a 4 chamber mainframe containing 3 distinct process types. Load locks are focused on in this experiment because of their likelihood to become a bottleneck within the tool for complex multi-process configurations. Each wafer must pass through a load lock before it can be processed in a chamber. If a chamber becomes idle and the load lock contains a wafer that needs to process on another chamber the idle chamber must wait until the load lock is free until its wafer can enter. A wafer may end up blocking a load lock for a long period of time while waiting for their required chamber to finish processing, cleaning, or come up from a down state.

Since efficiencies are lost when a tool is configured with multiple process type chambers this configuration is not recommended in a large manufacturing environment. Tool throughput and parts per hour (PPH) will be maximized when all chambers on the tool run with the same process type and processes do not need to compete for robot, load lock, and load port resources. However, when only 1 or 2 chambers total of a process type are required it is cost effective to place multiple process types on a single mainframe. This paper attempts to optimize PPH given a complex multi-process chamber configuration.

This paper consists of the following sections:

- Section 2 provides a literature review to provide background on research for chamber and cluster tool logistics.
- Section 3 goes through the configuration of the cluster tool used for this experiment.
- Section 4 gives an overview of the simulation model.
- Section 5 describes the methodology of the experiment.
- Section 6 lists results
- Conclusions are discussed in section 7.
- Section 8 provides other considerations and future work possibilities.

2 RELATED WORK

A large amount of research has been performed in the area of modeling cluster tools. Various tools have been used in the models. Among these, Srinivasan (1998) made use of Petri nets. Multiple papers, including Poolsup and Deshpande (2000) have modeled cluster tools with simulation models.

Papers strive to optimize the performance of cluster tools by different methods. Unbehaun and Rose (2007) present a method of predicting cycle times resulting from parallel processing in cluster tools that could be used in load port scheduling strategies.

LeBaron and Domasche (2005) performed a simulation experiment to comparing dedicated and non-dedicated load locks on a cluster tool with two process types. The study showed that most scenarios produced a higher throughput when allowing all process types to use both load locks. The work presented in this paper expands on their load lock dedication experiment by allowing for a more complex tool layout with 3 process types and a greater variation in processing times.

978-1-4244-2708-6/08/$25.00 ©2008 IEEE

The experiment that is presented in this paper is best used in conjunction with the research already performed. This methodology can be used to determine optimal load lock dedication to further improve productivity of a cluster tool for the tool configuration and load port scheduling algorithms that has been selected.

3 CHAMBER TOOL CONFIGURATION

The chamber tool used in this simulated experiment processes 1 wafer at a time in a vacuum. The configuration is shown in Figure 1.

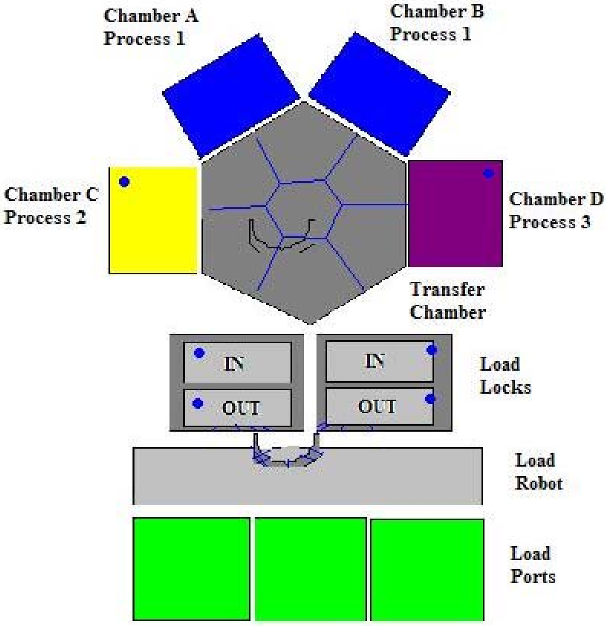

Figure 1: Chamber tool layout

A lot container or front opening unified pod (FOUP), containing 25 wafers, lands on one of the three load ports. Each load port can support 1 FOUP at a time. The rest of the tool locations, which include 4 chambers 2 robots and the "IN" and "OUT" slots of 2 load locks, can contain only 1 wafer at a time. Each wafer is taken from the load port by the load robot and placed in the "IN" slot of one of the two load locks. The load lock pumps to vacuum pressure before the transfer chamber robot places the wafer in the process chamber. This tool has 3 types of process chambers. Chambers A and B are duplicate chambers of process type 1. Chamber C is process type 2. Chamber D is process type 3. Each wafer of a lot processes in only one chamber. All wafers of a lot will process in the same process type chamber mandated by the recipe. For example, all wafers from lots of process type 2 will process in chamber C and all wafers from a lot of process type 1 will process either in chamber A or chamber B, alternating wafers from the same lot. After processing the transfer chamber robot transports the wafer from the chamber to the "OUT" slot of the load lock. The load lock then vents to atmospheric pressure. Lastly, the load robot return the wafer to its FOUP on the load port.

The tool runs in a parallel mode, meaning if multiple lots are on the tool the load robot will rotate which load port the next wafer is picked from. If 3 lots are on the tool each for a different process type then all chambers could be run simultaneously.

The "IN" slots for the load locks can be dedicated by process type. For example, process type 1 can be restricted to load lock A only, load lock B only, or can be left free to use both load locks.

4 SIMULATION MODEL

Using the tool configuration described in Section 3, a discrete event simulation model was built in ProModel version 7. FOUPS arrive to the tool from a distribution based on actual fab operating levels. All of the chambers are moderately loaded with utilizations shown in Table 1. Multiple recipes are processed on each process type. Process 2 is a fast process, process 3 is a relatively slow process, and process 1 is in the middle. The average recipe times for processing in the chamber are also listed in Table 1.

Table 1: Utilization and process time by process type.

Process Type	Chamber Utilization	Average Process Time (sec)
Process 1	51%	230
Process 2	42%	90
Process 3	29%	420

5 METHODOLOGY

The experiment is set up as a factorial design with 3 factors: process type 1 load lock dedication, process type 2 load lock dedication, and process type 3 load lock dedication. Each factor has 3 levels: dedication to load lock A only (LLA), dedication to load lock B only (LLB), and the ability to run through both load locks (DUAL).

Five simulation replications are run for each combination of dedication for a total of 135 data points. Each run is 30 days long with a warm up period of 1 day.

Statistics are collected on average PPH for each of the process types along with overall PPH for the tool.

ANOVA is used to determine if a statistically significant difference exists in PPH between the different dedications. Means are compared to determine the optimal load lock dedication for this tool and loading.

6 RESULTS

Raw data output from the simulation runs was analyzed with Minitab 15. This section contains results for average PPH for each of the process types along with overall PPH for the tool

6.1 PPH for Chambers A and B

An ANOVA on the PPH for chambers A and B show load lock dedication for each process type provide a statistical difference in PPH within a 99% confidence level. The interactions between all pairs of the factors are also significant. The ANOVA table, along with P-values, is included in Appendix A.

The top 3 and bottom 3 load lock dedication schemes for average PPH on chambers A and B are shown in Table 2.

Table 2: Dedication results for PPH of Chambers A and B.

Rank	Process 1	Process 2	Process 3	AB PPH
1	Dual	LLA	LLA	22.7
2	Dual	LLB	LLB	21.6
3	Dual	LLA	LLB	20.8
…				
25	LLB	Dual	LLB	11.0
26	LLB	LLB	Dual	9.9
27	LLB	LLB	LLB	9.6

6.2 PPH for Chamber C

An ANOVA on the PPH for chamber C shows load lock dedication for each process type provide a statistical difference in PPH within a 99% confidence. The interactions between all pairs of the factors are also significant. The ANOVA table, along with P-values, is included in Appendix A.

The top 3 and bottom 3 load lock dedication schemes for average PPH on chambers C are shown in Table 3.

Table 3: Dedication results for PPH of Chamber C.

Rank	Process 1	Process 2	Process 3	C PPH
1	LLA	Dual	LLA	27.6
2	LLB	LLA	LLB	27.2
3	LLA	Dual	LLB	27.0
…				
25	Dual	LLB	Dual	15.9
26	LLB	LLB	LLB	14.5
27	LLB	LLB	Dual	14.4

6.3 PPH for Chamber D

An ANOVA on the PPH for chamber D show load lock dedication for each process type provide a statistical difference in PPH within a 99% confidence level. The interactions between all pairs of factors are also significant. The ANOVA table, along with P-values, is included in Appendix A.

The top 3 and bottom 3 load lock dedication schemes for average PPH on chambers D are shown in Table 4.

Table 4: Dedication results for PPH of Chamber D**.**

Rank	Process 1	Process 2	Process 3	D PPH
1	LLA	Dual	Dual	7.3
2	LLA	LLA	LLB	7.3
3	LLB	LLA	Dual	7.2
…				
25	Dual	LLB	LLB	4.3
26	Dual	Dual	LLA	3.9
27	Dual	Dual	LLB	3.8

6.4 Total PPH for the tool

An ANOVA on the total PPH for the tool show load lock dedication for each process type provide a statistical difference in PPH within a 99% confidence. The interactions between all pairs of the factors are also significant. The ANOVA table, along with P-values, is included in Appendix A.

The top 3 and bottom 3 load lock dedication schemes for average PPH for the entire tool are shown in Table 5.

Table 5: Dedication results for total PPH of tool.

Rank	Process 1	Process 2	Process 3	Total PPH
1	LLB	LLA	LLA	20.2
2	Dual	LLA	LLB	19.9
3	Dual	LLA	LLA	19.8
…				
25	LLA	LLA	LLA	13.2
26	LLB	LLB	Dual	11.5
27	LLB	LLB	LLB	10.5

7 CONCLUSIONS

This simulation experiment has illustrated the large impact load lock dedication can have on the PPH of a tool in a high mix multi-process environment. Looking at the results for the total tool there was a 90% improvement in average PPH when moving from the worst dedication scheme to the best. Each of the individual chambers showed similar results, all showing a statistically significant difference.

Not surprisingly, dedication of all 3 process types to the same load lock ranked among the worst scenarios for the PPH of all chambers. This scenario leaves one of the available load locks unused.

The basic dedication of running all process types through both load locks did not show up among the top ranked dedication schemes for PPH on the entire tool or any of the individual processes. Setting up all recipes with a standard dual load lock setting can result in a significant loss of productivity.

Total PPH and AB PPH share 2 out of 3 top ranked dedication schemes. Each of these two dedication schemes give Process 1 use of both load locks. Since Process 1 includes two chambers, with the highest loading on the tool, it follows that setting up the dedication to favor Process 1 will improve the overall PPH of the tool.

The top dedication schemes are not shared across process types. In fact, a dedication in the top 3 for Chambers A and B (Dual for Process 1, LLB for Process 2, and LLB for Process 3) actually ranks in the bottom 3 for Process 3. Tradeoffs will have to be made in the importance of PPH for each process type to determine the optimal dedication.

Since this experiment only used a single product mix these results cannot be applied to all loading scenarios. Also, differences in tool configurations and internal logistics software could change the optimal dedication. However, these results provide insights into the importance of optimal load lock dedication.

8 FUTURE WORK

The next step in this work is to repeat the experiment for other loading scenarios and chamber configurations. Comparing results will determine common optimal dedication schemes to create heuristics and general rules of thumb for dedication.

There are also other methods to increase productivity that can be combined with this work. Some examples are altering scheduling restrictions on load ports, robot logic, and tool configurations.

ACKNOWLEDGMENTS

Eric Krall for his work on the simulation model used for this experiment.

A APPENDICES

Table 6: Analysis of Variance for AB PPH

Source	**DF**	**SS**	**MS**	**F**	**P**
AB	2	644.92	322.46	220.10	0.00
C	2	216.51	108.25	73.89	0.00
D	2	172.38	86.19	58.83	0.00
AB*C	4	410.84	102.71	70.11	0.00
AB*D	4	364.80	91.20	62.25	0.00
C*D	4	20.99	5.25	3.58	0.01
AB*C*D	8	30.93	3.87	2.64	0.01
Error	108	158.23	1.47		
Total	134	2019.60			

Table 7: Analysis of Variance for C PPH

Source	**DF**	**SS**	**MS**	**F**	**P**
AB	2	385.31	192.66	148.53	0.00
C	2	683.92	341.96	263.64	0.00
D	2	86.93	43.46	33.51	0.00
AB*C	4	900.53	225.13	173.57	0.00
AB*D	4	28.10	7.02	5.42	0.00
C*D	4	231.60	57.90	44.64	0.00
AB*C*D	8	30.44	3.81	2.93	0.01
Error	108	140.08	1.30		
Total	134	2486.91			

Table 8: Analysis of Variance for D PPH

Source	**DF**	**SS**	**MS**	**F**	**P**
AB	2	35.58	17.79	146.90	0.00
C	2	13.63	6.81	56.27	0.00
D	2	55.81	27.90	230.44	0.00
AB*C	4	10.27	2.57	21.20	0.00
AB*D	4	34.11	8.53	70.41	0.00
C*D	4	12.94	3.24	26.72	0.00
AB*C*D	8	0.95	0.12	0.98	0.45
Error	108	13.08	0.12		
Total	134	176.36			

Table 9: Analysis of Variance for Total PPH

Source	**DF**	**SS**	**MS**	**F**	**P**
AB	2	75.17	37.59	28.35	0.00
C	2	78.67	39.34	29.67	0.00
D	2	96.14	48.07	36.26	0.00
AB*C	4	441.32	110.33	83.23	0.00
AB*D	4	130.67	32.67	24.64	0.00
C*D	4	41.73	10.43	7.87	0.00
AB*C*D	8	10.00	1.25	0.94	0.49
Error	108	143.17	1.33		
Total	134	1016.88			

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AUTHOR BIOGRAPHIES

JULIE CHRISTOPHER is an Industrial Engineering Module Lead for IBM's 300mm Semiconductor Fab in Fishkill, NY. The IE module she leads consists of the Reactive Ion Etch, Rapid Thermal Process, and Insulator sectors. She received her BS and MS in Industrial and Systems Engineering from the Rochester Institute of Technology. She has published past conference papers with a focus on simulation within the semiconductor industry for the Winter Simulation Conference and the International Symposium on Semiconductor Manufacturing. Her email address is <juliech@us.ibm.com>.