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CLUSTER TOOL SIMULATION ASSISTS THE SYSTEM DESIGN

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ABSTRACT

Designing semiconductor cluster tool systems is a complicated task due to the nature of automatic operations and various configurations of modules and task response priorities of robots. System designers have to synchronize the wafer processing time of each module with robot operation times in order to obtain maximum throughput from the system. A simulation model was developed to reflect the process flows of wafers to and from wafer carriers through various modules in the cluster tool system. The model was first utilized to ascertain the best system configuration of the proposed systems, then utilized to design a cluster tool system that will meet the specific customer requirements.

1 PROJECT BACKGROUND

A cluster tool manufacturer proposed new designs of two cluster tool systems, an independent deposition modules system and an integrated deposition modules system. The cluster tool systems consist of the following components: wafer carrier, Aligner, Dual Wafer Load Lock(DWLL), Degas Station, Process Modules, Cooling Station, and two wafer handling robots.

A simulation model of the cluster tool system was developed to identify what configuration of robot (2 arms or 1 arm) and what priorities of the robot logic affect the throughput of the system. The model reflected the detailed flow of wafers from

- the wafer carrier to the Aligner
- the Aligner to the Dual Wafer Load Lock Modules
- the Dual Wafer Load Lock Modules to the Degas Station
- the Degas Station to the Process Modules(PM)
- the Process Modules to the Cooling Station(CS)
- the Cooling Station to the Dual Wafer Load Lock Units
- the Dual Wafer Load Lock Modules back to wafer carriers.

The model was developed to analyze the system before committing the design of the system and was utilized to quantify the effect of system configurations and robot logic on the throughput of the system. The desired benefit of the simulation analysis was to determine the system design that would result in the maximum throughput.

2 SYSTEM DESCRIPTION

The model focused on task response priority of the robots and detailed flow of wafers through various modules in the system. There are two modules in the cluster tool systems under study. The first part consists of the wafer carriers, Aligner, and an atmospheric robot. This part of the system operates at atmospheric pressure. The second part of the system consists of the Degas Station, Process Modules, Cooling Stations, and a vacuum robot. This part of the system operates at a vacuum pressure. Dual Wafer Load Lock Units connect the two parts of the system.

The wafer states and their flow through the system is shown in Figure1.Wafer processing starts when wafers in the wafer carriers are transported by an atmospheric robot to the Aligner. After processing at the Aligner, the wafers are transferred to the Dual Wafer Load Lock, where the vacuum robot transfers them to various process modules depending on the system type. For the independent deposition modules system, wafers will move from the load lock to a Process Module, a Cooling Station, back to the load lock, and then to the wafer carrier. For the integrated deposition modules system, the wafers will move from the load lock to an optional Degas/Preheat module, a first Process Module, a second Process Module, a Cooling Station, back to the load lock, and then to the wafer carrier. Wafers coming out of the load lock will be placed into the original wafer carrier.

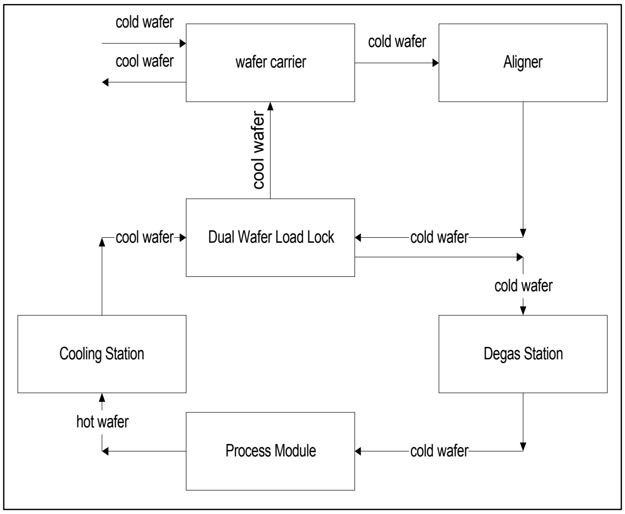

Figure 1: Flow of Wafers through the System

Figure 2 shows the tasks assigned to the robot operating at atmospheric pressure.

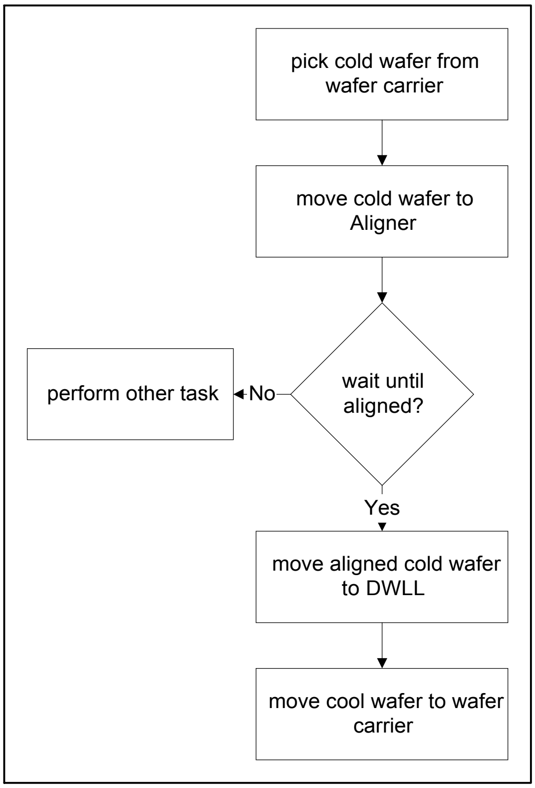

Figure 2: Atmospheric Robot Tasks

Figure 3 shows the tasks assigned to the robot operating in the vacuum and interacting with the DWLL, Degas Station, Process Module, and Cooling Station.

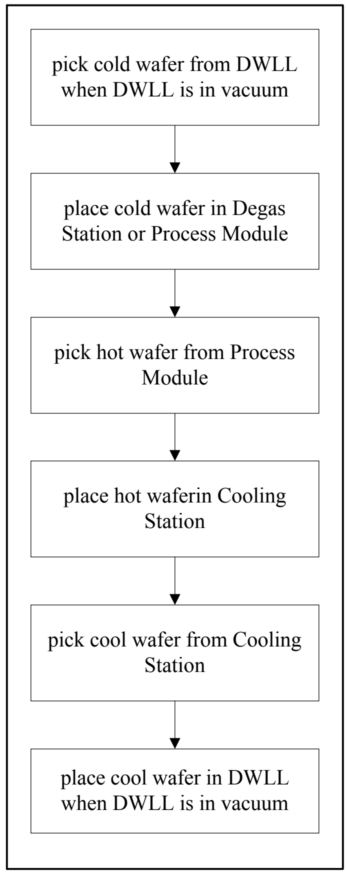

Figure 3: Vacuum Robot Tasks

Figure 4 shows the system process flow for an independent deposition modules system and an integrated deposition modules system.

3 KEY ASSUMPTIONS

All Process Modules are identical and the maximum number of Process Modules in the system is four. The effect of error conditions at the Process Modules was not modeled.

4 SYSTEM PERFORMANCE MEASURES

Analysis of the system was based on the following performance measures reported by the simulation model summary reports: A representative table of results is shown in the appendix of the paper.

1. Average throughput per hour from the system, and for each Process Module. This allowed us to quantify the total throughput of the system as well as the effect of each Process Module on system throughput.

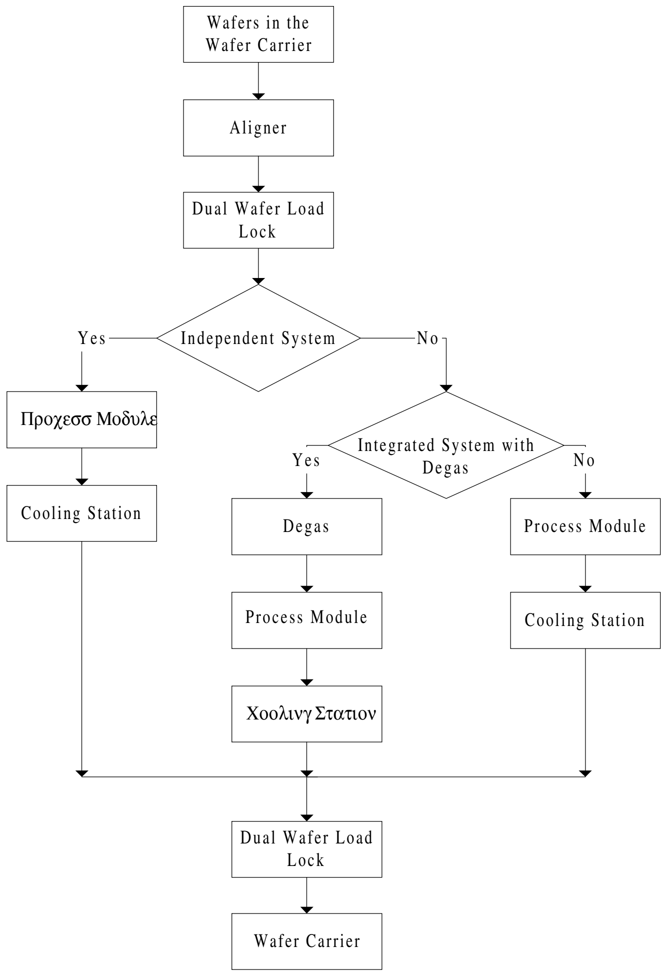

Figure 4: The System Process Flow

2. The minimum, average, and maximum time that a wafer remains in the Process Module in excess of the maximum allowable time and the percentage of wafers that exceed the maximum allowable time in the Process Module. This was utilized to quantify the effect of the vacuum robot logic on the transferring of wafers from the Process Module to the Cooling Station.
3. Percentage of hot wafers that are unloaded without an exchange of a cold wafer. This allowed us to quantify the advantage of having the two arm vacuum robot prepare a cold wafer for loading into the Process Modules.
4. The minimum, average, and maximum time between wafers arriving at a Process Module. This allowed us to quantify the effect of various robot configurations and task response priorities in relation to the supply of wafers to the Process Modules.
5. Utilization rate of the vacuum and atmospheric robot arms. This allowed us to identify the best vacuum and atmospheric robot configurations and task priorities.
6. Utilization rate of the Process Modules and the Cooling Station. This allowed us to determine the optimum number and configurations of the Process Modules and the Cooling Station.

5 SIMULATION RUN TIME PARAMETERS

The model was run for 40 hours (5 days with 8 hour shifts) with a warm-up period of 8 hours. Since the model starts with an empty system, the warm-up period was decided by plotting the total throughput per hour over a period of 40 hours. Based on this plot it was decided to have a warm-up period of 8 hours so that the system reaches a steady state. The number of replications was decided based on the confidence interval of the output parameters. Since there was not a high variability in the results the number of replications was set at 10.

6 EXPERIMENTATION

The experimentation of the model consisted of scenarios with the combination of various input factors listed in Table 1.

Table 1: Experimental Parameters

Input Factor	Levels	Purpose
Number of wafer carriers	1. Two 2. Four	Determine optimum number of carriers
Dual Wafer Load lock capacity/tasks	1. As Input and Output 2. One Input and one output	Test effect of load lock configuration
Vacuum Robot Arms	1. One Arm Robot 2. Two Arm Robot	Test the effect on throughput of the system.
Cooling Station capacity	1. Four 2. Two	Determine optimum capacity.
Degas Station configuration	1. Independent System 2. Integrated system	Test the effect on throughput of the system.
Vacuum robot priority	1. Changing the priorities of DWLL unload, PM unload, CS unload	Test the effect on throughput of the system.
Atmospheric robot priority	1. Waiting at the Aligner when wafer is aligned 2. Not waiting at aligner	Test the effect on the throughput of the system.

7 RESULTS

From the simulation results, it was found that for both the two arm vacuum robot model and one arm vacuum robot model with independent system and DWLL as input/output, all the experiments have almost the same throughput and there is no factor that has significant effect on the throughput of the system.

For both the two arm vacuum robot model and one arm vacuum robot model with independent system with 1

DWLL as input and 1 DWLL as output, the factors that affect the throughput of the system are cooling station capacity, priority of the vacuum robot, and whether the atmospheric robot waits at the aligner or not. Figure 5 shows the effect of priority of the vacuum robot on the throughput of the system for the two arm model.

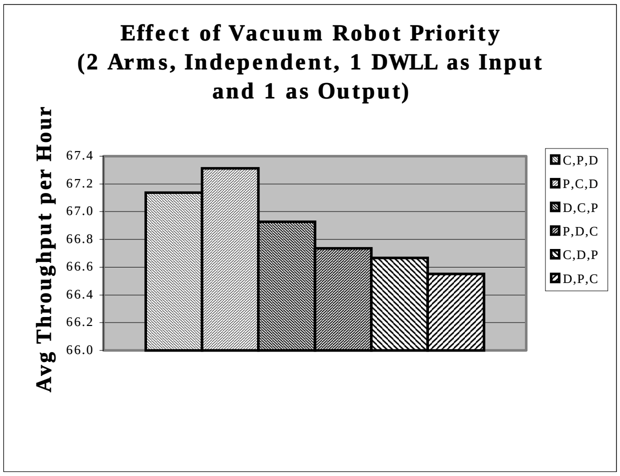

Figure 5: Effect of Vacuum Robot Priority

For both the two arm vacuum robot model and one arm vacuum robot model with integrated system there is no factor that has significant effect on the system throughput . It was found that the number of wafer carriers required is two, for both independent deposition modules system and integrated deposition modules system. From Figure 6 it can be seen that having more than two wafer carriers in the system has no significant effect on the throughput.

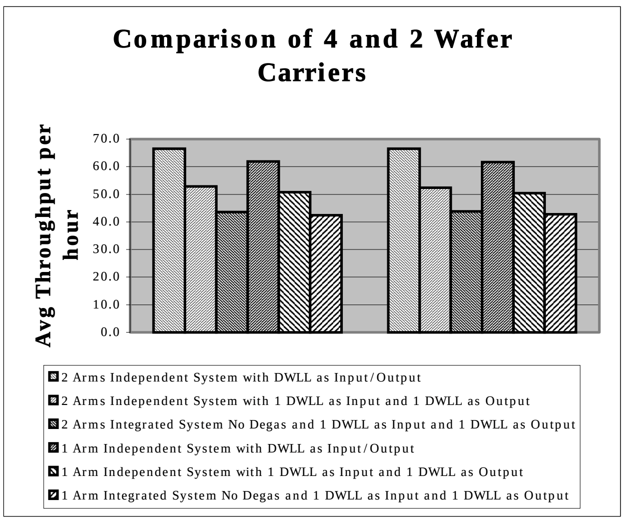

Figure 6: Comparison of Throughput of 4 and 2 Wafer Carrier Systems

For the independent deposition modules system (Figure 7), it was determined that the configuration of the Dual Wafer Load Lock has a significant effect on the throughput. When the load locks both perform the input/output function, the throughput was increased by 25% from when one load lock performs input and one performs the output function. On the other hand, the configuration of the Dual Wafer Load Lock has an insignificant effect on the throughput of the integrated deposition modules system.

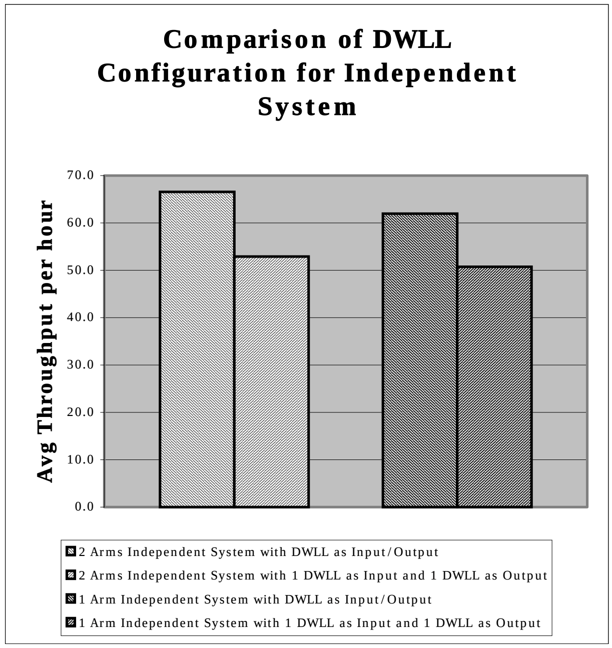

Figure 7: Comparison of DWLL Configuration for Independent System

In both systems, when comparing the throughput of the system with a one arm atmospheric robot to the throughput of the system with a two arm atmospheric robot, it was shown that adding an additional robot arm has no significant benefit on the system throughput.

For both independent and integrated deposition modules systems, the optimum capacity of the Cooling Station should be two. A capacity of greater than 2 for Cooling Station module was shown to have no significant benefit to system throughput.

8 SUMMARY

The simulation model created for this analysis allowed the cluster tool manufacturer to determine which of the cluster tool system designs under consideration for development should be pursued. In addition, the manufacturer utilized the model to determine what system modifications they must make to achieve specific requirements of their customers.

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APPENDIX: EXPERIMENTAL RESULTS

Table A-1: Sample Result for 2 Arms Vacuum Robot Model with DWLL as Input and Output

	Experiments									
Input factors	**Base**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Cooling Station Capacity	4		2							
DWLL Capacity	2									
Number of FOUP/SMIF/Cassettes	4	2								
DWLL Task:1=input/output, 0=one for input & one for output	1									
Robot priority: DWLL unload, PM unload, Cooling tray unload	DW, PM, CL					PM, DW, CL	CL, DW, PM	CL, PM, DW	DW, CL, PM	PM, CL, DW
Atm Robot Task at Aligner: 0 = waiting, 1 = no waiting	0			1						
Integrated Module: 0 = No, 1 = Yes	0									
Degas Module: 0 = No, 1 = Yes	0									
Degas Capacity	0									
Vacuum robot preposition for next task: 0 = No, 1 = Yes	0				1					
Model results										
PM1 percent operation	94.66	94.68	91.74	94.92	95.04	95.04	95.12	95.50	95.52	95.64
PM2 percent operation	93.19	93.16	90.20	93.48	93.42	93.51	93.37	94.09	93.80	94.34
PM3 percent operation	93.20	93.18	90.10	93.48	93.43	93.47	93.38	94.07	93.83	94.30
PM4 percent operation	95.06	95.26	92.08	95.28	95.08	95.16	95.62	95.86	96.04	95.86
PM1 percent waiting	1.37	1.42	1.31	1.56	1.53	1.47	1.34	1.42	1.48	1.34
PM2 percent waiting	1.70	1.75	1.64	1.89	1.86	1.80	1.67	1.75	1.81	1.67
PM3 percent waiting	2.05	2.16	1.31	1.42	1.76	1.70	2.08	1.41	2.05	1.38
PM4 percent waiting	2.02	2.13	1.28	1.39	1.73	1.67	2.05	1.38	2.02	1.35
Cooling tray percent utilization	60.36	60.57	25.94	58.21	59.91	58.89	58.62	56.45	56.46	55.45
PM1 Total wafers processed	444	444	430	446	444	445	445	448	446	449
PM2 Total wafers processed	444	443	429	445	444	445	445	447	446	449
PM3 Total wafers processed	443	444	428	445	444	445	445	448	446	449
PM4 Total wafers processed	444	443	428	445	445	444	445	448	446	449
Average throughput/hr.	66.6	66.5	64.3	66.8	66.7	66.7	66.7	67.1	66.9	67.3
Percent not exchange	35.82	35.59	48.90	31.91	34.34	37.09	32.68	32.64	29.20	28.93
Percent vacuum robot left arm utilization	51.12	51.24	46.21	53.30	52.00	53.42	49.25	53.16	55.11	55.25
Percent vacuum robot right arm utilization	55.58	54.95	48.84	58.26	56.62	55.48	55.61	56.65	59.15	58.06
Percent atm robot utilization	30.50	29.82	29.42	30.55	30.56	30.57	30.55	30.77	30.67	30.85
Percent exceed allowable time	0.69	0.88	0.92	0.34	0.26	0.15	0.54	0.03	1.90	0.02
Average time of wafers that exceed allowable time (sec)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM1 average time between wafer arrival	325.2	325.2	336.3	324.0	324.6	324.0	324.3	322.4	323.2	321.6
PM2 average time between wafer arrival	325.1	325.1	336.7	323.9	324.5	324.1	324.2	322.2	323.1	321.3
PM3 average time between wafer arrival	325.1	325.5	336.8	323.8	323.9	324.3	324.3	322.0	322.9	321.0
PM4 average time between wafer arrival	111.2	116.2	99.2	105.8	85.0	116.6	63.0	90.5	82.9	155.5