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EVALUATION OF CLUSTER TOOL THROUGHPUT FOR THIN FILM HEAD PRODUCTION

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ABSTRACT

This paper describes the application of simulation for analyzing cluster tool cycle times and cluster tool capacity planning. The objective of this project was to develop a flexible and expandable tool for rapidly calculating tool cycle times for a multiple step process through alternative tool configurations. The calculated process cycle times are then used to calculate equipment tool set requirements against product demand. The Seagate Industrial Engineering group utilized a simulation based cluster tool model developed to predict cluster tool cycle times and analyze cluster tool capacity across multiple tools and compare with results from static probability based model predictions.

1 INTRODUCTION

The production of thin film heads for use in hard drive storage technologies has become an extremely capital-intensive venture. Wafer fabrication of thin film heads uses many processes found in the semiconductor industry (i.e. photolithography, vacuum metal deposition, chemical etching, etc.) Of the more than 100 advanced tools used in the thin film head manufacturing process, the cluster deposition tool (cluster tool) is a particularly significant capital investment, therefore requiring careful planning. Cluster tools are used in thin film head manufacturing to deposit sequential magnetic or conductive metal layers; these depositions typically occur under high vacuum conditions. The primary processing advantage of the cluster tool in this application is the ability to deposit sequential films without exposure to atmosphere between deposition steps. Other advantages to clustering process modules include rapid reconfiguration, reduced cycle time, reduced handling, and smaller cleanroom space requirements (Singer, 1995). Cluster tool processing reduces the risks of particulate contamination and film oxidation during processing, both of which negatively impact product yield. Cluster tools represent a unique capacity planning challenge in terms of defining optimal configurations, calculating throughput, and calculating the number of tools needed to meet production demands.

The basic components of a cluster tool are an input/output station, a central robotic wafer handler, and the individual process modules. Such a tool is shown below in Figure 1, with representative target materials labeled A – F on the appropriate process module.

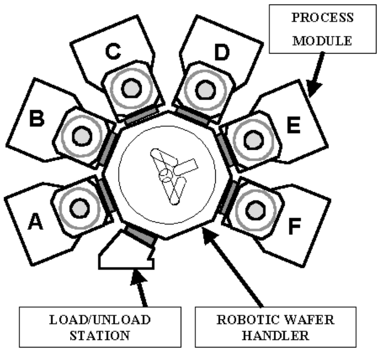


Figure 1: Cluster Tool Components

The integrated cluster tools are configurable for operation in either serial or parallel processing. The notion of serial and parallel processing tools is illustrated in Figure 2. As shown, a serial process would complete deposition steps sequentially in modules A-B-C-D. The parallel processing tool shown allows simultaneous deposition of material A in the four modules.

Evaluation of serial vs. parallel systems by Lopez and Wood (1996) indicates that parallel-configured tools can offer higher throughputs, but cautions that this advantage is reduced when down time is predictable and infrequent. Based on this, it was evident that evaluation of cycle time performance under perfect reliability and under observed failure modes would be needed for this project.

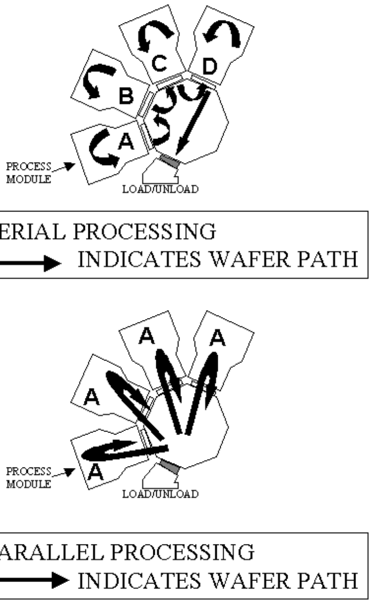


Figure 2: Serial vs. Parallel Processing

The cluster tools to be studied can have up to six process modules, one or two load/unload stations, and a robotic handler with a single end effector. The load/unload stations are configured to hold up to twelve wafers. Each process module is able to process a single wafer, depositing a single target material. A tool may have duplicate modules (target materials) docked on the handler, and these modules may process wafers simultaneously. In the case of a tool configured with duplicate modules for process, partial and full cluster module availability throughput rates would need to be simulated.

A typical thin film head product may require up to five distinct deposition operations. Production demand was calling for up to five generations of products to be built simultaneously, each generation needing slightly variant depositions. The timeline and materials requirement for one magnetic feature is shown below and illustrates the need for multiple configurations of tools at any given time. Typical product timeline overlap is shown in Figure 3. The challenge is determining the optimal configuration for individual tools as well as determining the total number of tools needed to meet schedule demands.

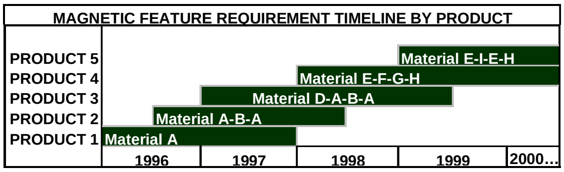


Figure 3: Typical Product Need for Magnetic Feature

2 MODELING APPROACH

The cluster tool planning method used consisted of the following major activities:

- Calculate individual operations process cycle times for tool for all feasible configurations
- Determine optimal configurations for the individual process tools.
- Use cycle times for all feasible operations for all tools to model to determine throughput across multiple tool system.
- Compare simulated multiple tool system throughput with probability based model throughput

The general approach is outlined below in Figure 4.

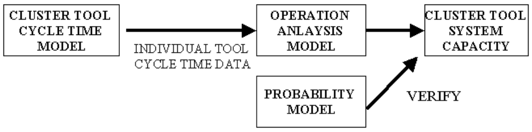


Figure 4: Flow Diagram for Cluster Tool Modeling Approach

2.1 Modeling Individual Tool Throughput Under Perfect Reliability

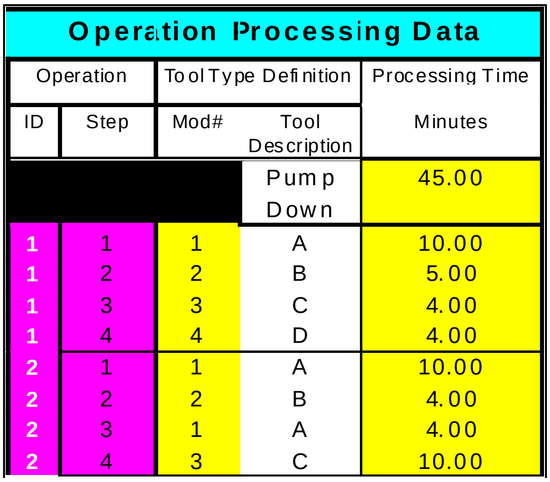
The basic inputs to the simulation model are entered into a generic template. The following time/motion inputs are used as inputs into the model:

- Robotic wafer transfer times
- Vacuum pumpdown of the input/output station
- Individual module process times
- Operator load/unload times

Because of their inherently contiguous nature, the vacuum pumpdown of the input/output station and the operator load/unload times are combined to a single time element. Additionally, the user can specify:

- Available minutes per day
- Number and type of modules
- Total wafer allowed in tool

The model generated by Productive Systems provided a familiar Excel spreadsheet interface for entering the above parameters. Shown below in Figure 5 is the input matrix for time/motion inputs.



Operation Processing Data

Operation		Tool Type Definition		Processing Time
ID	Step	Mod#	Tool Description	Minutes
			Pump Down	45.00
1	1	1	A	10.00
1	2	2	B	5.00
1	3	3	C	4.00
1	4	4	D	4.00
2	1	1	A	10.00
2	2	2	B	4.00
2	3	1	A	4.00
2	4	3	C	10.00

Figure 5: Input Matrix for Cluster Tool Process

The input matrix in Figure 5 depicts the processing parameters for two operations, each requiring four serial depositions. For operation ID #2, a minimum tool configuration would be a three module tool: A-B-C. However, based purely on process times, an optimal tool with six processing modules would be configured as:

A-A-B–A-C-C. Relative cycle times for all possible configurations between three and six module tools could be readily simulated.

2.2 Modeling Throughput for a System of Multiple Cluster Tools – Operation Analysis Model

The simulation model developed by Productive Systems tracks the flow of wafer cassettes through a collection of cluster tools and estimates the effective capacity of the user defined system. Mean time between failure (MTBF) and mean time to repair (MTTR) data is an input for each unique cluster tool component. A fixed number and mix of cassettes are introduced into the model at the start of each simulation day. The model operates on an individual cluster tool basis. When a cluster tool completes the processing of a cassette, the cluster tool status is checked. If the cluster tool robot arm has failed, no new work can be considered until that failure has been cleared. A cluster tool with an available robot arm is checked for module status. If one or more modules are available, a search for feasible work is made. This search is based on the number of available modules that each potential cassette can utilize. Priority is given to cassettes that use the maximum number of available modules, thereby attempting to maximize tool throughput.

When a cassette has been selected for processing, processing on the cluster tool is started following a randomly generated gap period. This gap period is used to simulate metrology feedback loops, operator inputs and other unavoidable delays. Once the processing of a cassette has started it continues to its scheduled completion without regard to cluster tool status. The cassette processing time depends on the cluster tool configuration selected and the current status of its modules.

Failed modules are placed in the repair status immediately after completing cassette processing and can return to service at any time. The return to service of a module has no immediate impact on the performance of an operating cluster tool. If the cluster tool is idle, a check for potential work is made immediately after each module repair is completed.

Cluster tools become idle when no suitable work can be found after processing all available cassettes. The model records when each cluster tool enters the idle state. If all cassettes can not be finished on a given day, the excess can be carried forward for future processing. At this point the carryover cassettes are aged one day. Within a given cassette type, the oldest cassettes are given priority and always processed first. Statistics are maintained on the age of cassettes as they complete processing. (Seppanen, 1998)

The model user must balance the number of cassettes entering the system each day with the effective capacity of the cluster tool system. There is little point in simulating a system with such limited capacity as to permit the WIP level to grow without an upper bound. The operating WIP level must be balanced by changing the mix of cluster tool modules or cassettes.

2.3 Combined Simulation Model Usage

In practice these two models are operated in the following manner. First the Cluster Tool simulation model is executed to determine a production standard in terms of minutes per cassette. A single cluster tool is simulated with a fixed operation input cassette and with a tool operating under perfect reliability to generate a standard time. This standard time represents the maximum possible throughput rate. One standard is generated for each possible cluster tool configuration and wafer operation. The final result is a set of best possible processing times for all operations being preformed on all feasible cluster tool combinations.

The Operation Analysis simulation model is executed after all possible individual cluster tool standard times have been generated using the Cluster Tool simulation model. Because the standard times have been generated without random variation due to downtime or operator performance, those factors must be incorporated into the Operation Analysis model.

2.4 Estimating System Throughput and Capacity Using Uptime Probabilities

A probabilistic throughput model for multiple tools was used to verify system throughputs predicted by the operation analysis model. Expected throughput for a given cluster tool is calculated by multiplying the probability of a tool being in a particular state by the throughput associated with that state. The probability of a tool being in a particular state is calculated by multiplying empirical uptime/downtime values for each component in the cluster tool. For an n-component cluster tool there are 2^n states. For example, the tool represented in Figure 1 has $2^7 = 128$ possible states, each with a characteristic throughput. Reliability data available from the maintenance organization was used for the robot handler and the individual process modules. Load/unload station failures are recorded with the robot handler failures, so the load/unload and the robot handler are considered a single component.

Tables 1 & 2 show a sample of a calculated throughput for a tool consisting of three components: the robot handler and two process modules. The calculation represents a tool running a single step deposition parallel process. Table 1 indicates the state for each component, either up or down. For the illustrated two-module tool, there are eight corresponding states. Five of these states represent zero throughput.

Table 1: Cluster Tool Event Space for a Two Module Tool

CLUSTER TOOL EVENT SPACE

ROBOT	MOD1	MOD2	TOOL	THROUGHPUT
Up	Up	Up	Up	100 %
Up	Up	Down	Up	< 100 %
Up	Down	Up	Up	< 100 %
Up	Down	Down	Down	0.0%
Down	Up	Up	Down	0.0%
Down	Up	Down	Down	0.0%
Down	Down	Up	Down	0.0%
Down	Down	Down	Down	0.0%

Table 2 details the calculation of predicted throughput using representative data from the maintenance tracking system for the percent up/down for each component. The Tput[state] values represent the throughput as model under perfect reliability from the individual tool simulation model. The E[Tput] values represent the expected throughput contribution for each state, and the sum of this column is the total expected throughput for the two-module tool. This method represented a simple and rapid method for comparing results from the operation analysis simulation model and arriving at an estimate for system capacity.

Table 2: Cluster Tool Throughput Calculation Matrix for a Two Module Tool

CLUSTER TOOL THROUGHPUT MATRIX

ROBOT	MOD1	MOD2	P(state)	Tput(state)	E[Tput]	
97.0%	50.0%	50.0%	24.3%	150.6	36.5	
97.0%	50.0%	50.0%	24.3%	85.5	20.7	
97.0%	50.0%	50.0%	24.3%	85.5	20.7	
97.0%	50.0%	50.0%	24.3%	0.0	0.0	
3.0%	50.0%	50.0%	0.8%	0.0	0.0	
3.0%	50.0%	50.0%	0.8%	0.0	0.0	
3.0%	50.0%	50.0%	0.8%	0.0	0.0	
3.0%	50.0%	50.0%	0.8%	0.0	0.0	
			100.0%	**Sum E[Tput]=**	**78.0**	**WAFERS/DAY**

3 RESULTS AND DISCUSSION

3.1 Individual Tool Throughput

Cycle time results for existing process tools were generated using the Arena cluster tool cycle time model. Of particular interest, with capital costs in mind, were cycle time results for proposed tool configurations. Results for a tool configured with one to four modules running a parallel deposition process are shown in Figure 6.

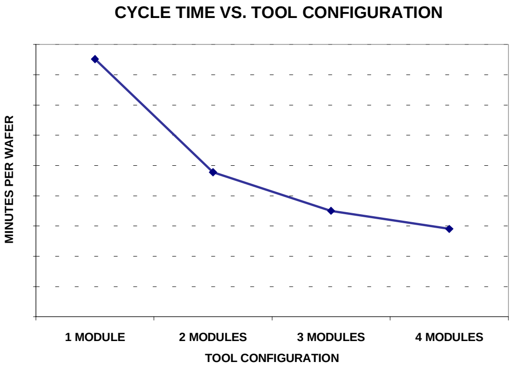


Figure 6: Predicted Cycle Time vs. Tool Configuration for Parallel Process Tool

The ratio of deposition time/robot time was greater than 15 (large), so it was interesting to find the effect of adding process modules on cycle time was non-linear. Detailed simulation results pointed to an increase in the percentage robotic working time with a corresponding increase in time that a wafer spent waiting for the robot to become available. Additionally, the amount of time that a module was ‘empty’ increased as well, these results indicated diminishing returns on adding additional modules (more than four) to this particular parallel processing tool. As the thickness deposition specifications have changed for this parallel process, the model has provided quick answers regarding impacts on tool cycle times. After study of this operation, the use of the model was expanded to develop time standards for all cluster tool operations on all feasible tool configurations.

3.2 Multiple Tool System Throughput Comparisons

The next phase of the analysis was to estimate throughput across multiple tools, with particular attention being paid to uptime considerations. As a starting point, a single-step parallel deposition process was evaluated. A system of two separate cluster tools was modeled with between one and four process modules on each central robotic handler.

For the uptime probability based model, uptime and downtime data from the maintenance history was used as input, and entered as percent uptime and percent downtime. Throughput was calculated for each tool configuration in a manner similar to that outlined in Table 2. Calculated throughput for each configuration between one and four modules was then multiplied by two, to represent an independent two tool system.

For the simulation based operations analysis model, MTTR and MTBF data were entered for the process modules and the robotic handler. The system forced to run at maximum capacity by starting over 400 wafers per day, well over the most optimistic estimates for the two-tool system.

A comparison of results between the simulation based model and the uptime based probability model is shown in Figure 7. Interestingly, the simulation model predicted 53% less throughput than the probability model for a pair of tools with one module on each tool. However, when comparing two tools with four modules on each tool, the difference in expected throughput nearly disappears. This has suggested that MTTR and MTBF data have a significant role in the predictive ability of these two models for evaluating systems of one and two module tools. The simulation based model conservatively estimates throughput for the two single module systems. Further investigation of this effect is ongoing, as it is important when introducing new products requiring unique tool configurations, especially when limited modules are available for building the necessary cluster tool.

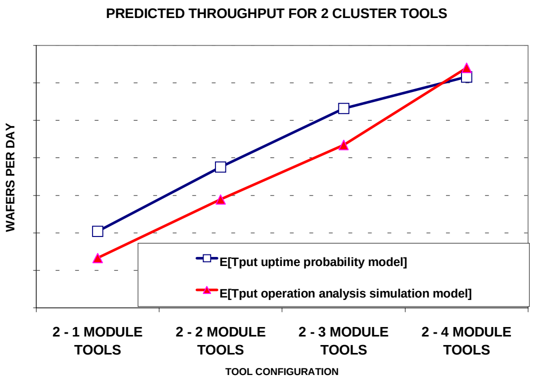


Figure 7: Predicted Throughput for 2 Cluster Tools

4 CONCLUSIONS

The models supplied by Productive Systems have provided the Seagate Industrial Engineering team with effective tools for analyzing cluster tool cycle times and for cluster tool capacity planning. The individual cluster tool throughput simulation model has proved to be a flexible and expandable tool for rapidly calculating tool cycle times for a multiple step process through alternative tool configurations. The operational analysis model is in use to evaluate cluster tool capacity across multiple tools, with particular interest to the effect of MTTR and MTBF on throughput estimates. The combined usage of the two simulation tools developed has enabled the Industrial Engineering group to effectively meet the challenge of planning capacity for systems of cluster tools.

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