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Inside

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A Cost of Ownership Model for Gas Distribution Systems

By: Helen Armer, Aeroquip Corporation

1. It's Difficult to Maintain Cleanliness in a Gas Distribution System

Current semiconductor manufacturing requires ultra-high purity (UHP) gases. Gas suppliers have developed the capability to produce gases with part per billion levels of impurities. Ultra-high purity gases are so pure that the weak link in gas delivery is often the gas distribution equipment. This equipment includes such components as piping, valves, filters, purifiers, mass flow controllers (MFC's), pressure regulators, pressure transducers, flow switches, and safety monitors.

To minimize contamination, cleanliness requirements for gas distribution equipment have increased. Specialty materials of construction (316L VIM/VAR, Elgiloy®, Hastelloy®)[1] and expensive surface finishing techniques (electropolishing, oxygen passivation, and chromium-rich passivation) are used. Tube bending is done reluctantly because of stress-related defects that cause contamination, and this necessitates welding fittings onto tubes. Welding adds expense, and welding processes are further complicated by the need to minimize the heat-affected zone's exposure to oxygen. All UHP gas distribution components are precision cleaned and assembled in a Class 100 or better cleanroom. Furthermore, there is little standardization of component sizes and interfaces, although a major thrust is underway to standardize various engineering features [1, 2]. These factors contribute to high cost and prevent the semiconductor industry from using more widely available gas conveying componentry.

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Editorial Board

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1999 Calendar of Events

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May

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7	SEMI-sponsored seminar "Understanding and Using Cost of Ownership" Singapore

July

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12-14	SEMICON West - Wafer Fab San Francisco, California
12	SEMI-sponsored seminar "Understanding and Using Cost of Ownership" for Wafer Fab San Francisco, California
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15	SEMI-sponsored seminar "Understanding and Using Cost of Ownership" for Assembly & Packaging San Jose, California

October

17-18	SEMI-sponsored seminar "How to Successfully Manage New Product Introductions" Austin, Texas
20	SEMI-sponsored seminar "Understanding and Using Cost of Ownership" Austin, Texas

November

8-10	SEMI-sponsored seminar "Managing and Marketing After Sales Support" Mt. View, California

COO Model... cont. from page 1

Cost is now becoming a key driver in purchasing decisions for gas distribution equipment. Hence, a tool for performing rigorous cost analysis is needed. In the semiconductor industry, the most commonly used tool for equipment lifetime cost analysis is Cost of Ownership (COO). This paper presents a COO model for gas distribution equipment. The model used the standard COO equations as defined in SEMI E35-95A [3]. Results are shown for gas sticks on a few process tools in a hypothetical 300mm wafer fab running 250nm design rule.

2. COO Model Development

The building block of a gas distribution system is a gas stick. This is an assembly of components that usually includes pressure and flow control, filtration, and valving. A process tool contains anywhere from four to forty sticks. Manifold boxes, isolation boxes, and other types of gas boxes feed these sticks. They are, in turn, fed by specialty gas cylinder cabinets or bulk gas storage tanks, all of which contain components and sticks. Most fabs have several thousand gas sticks.

When a component in a process tool gas box fails, the following scenario unfolds. Production shuts the tool down and releases it to Maintenance. Maintenance removes the suspect component (or stick) and obtains a replacement per some maintenance agreement. The replacement component (or stick) arrives and is installed. The system is leak checked and purged, and the tool is released to Production. Production runs a test wafer to validate that the tool is within specification, and returns the tool to service. The entire procedure takes anywhere from six to twenty-four hours. Fab throughput is impacted, and if the failure was due to corrosion, particle shedding may have caused die yield loss.

The work presented here captured costs associated with installing, operating, and maintaining a process tool gas box. To “normalize” the results, one gas stick in the box is modeled. COO for a given process tool gas box is simply the product of COO for one stick and the number of sticks in the box.

Figure 1 shows the gas stick used in this analysis. All components except the filter and MFC are treated as capital with a useful life equal to the stick life, which is five years for this analysis [3, 5]. The filter and MFC are treated as consumables. A filter life of five years was used for all cases based on lifetimes advertised by filter manufacturers. This means that in our hypothetical stick the filter is never replaced. However, it is treated as a consumable for depreciation purposes. The MFC life was varied from six months to five years. This range is representative based on conversations with various industry experts. Maintenance is done only when a component fails. All cases are built around the scenario of MFC failure. Two maintenance philosophies are considered: (1) only the MFC is replaced, and (2) the entire stick is replaced. All cases represent a fab line running 300mm wafers with 250nm design rule. Equipment specifications were taken from the I300I Equipment Performance Metrics [5]. Typical component prices were used. The maintenance procedure represents the “best practice” of a gas box assembler [6]. Tables I and II list inputs to the model.

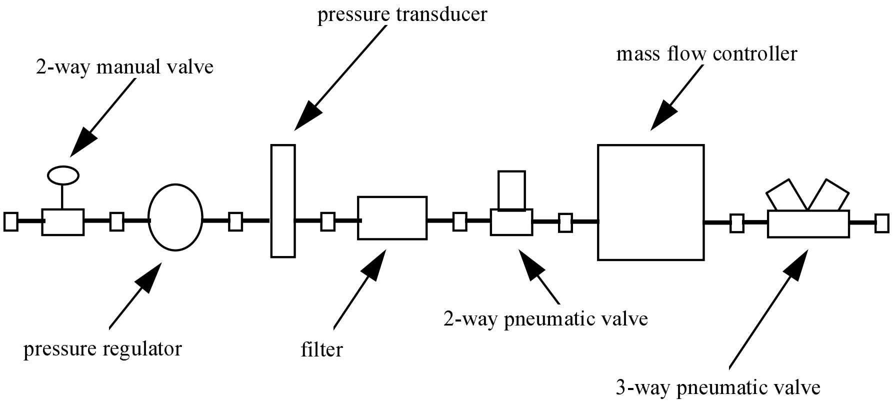

Figure 1. Gas stick modeled.

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COO Model ... cont. from page 3

Some costs that are normally included in a COO analysis were not included in this analysis. Environmental Safety Health (ESH) permits and ESH impacts were excluded, as was transportation. Utilities, insurance, and property tax were zero per I300I Equipment Performance Metrics [5]. The model assumes that there are no annual training costs associated with gas boxes. Salaries for administration and contract labor are excluded [5]. Also, the cost of purge gas was excluded since it is very small. Purge gas is nearly always UHP nitrogen, which is usually generated on-site or delivered in large quantities. The amount consumed for purging during gas box maintenance is negligible relative to other uses and does not affect the total fab requirement. Hence, purge gas is essentially free. The cost of the process gas was also excluded since it is process recipe specific.

Table I. Inputs to the COO Model.

This table contains values for those inputs that are common for all cases. Inputs that vary with case have a check mark in the last column. Values for these inputs are listed in Table II.

Category	Parameter	Value	Units	√ if Variable
Reliability Availability Maintainability Data	Scheduled Maintenance Downtime	0.00	hrs./week	
	Mean Time To Test	0.25	hrs./test	
	Mean Time Between Failure			√
	Average Response Time	0.33	hrs.	
	Mean Time To Repair	6.91	hrs.	
	Cost to Production per Failure Event	560	$/event	
	Mean Time To Restart Production	1.25	hrs.	
	Fab Production Cost per Failure			√
Financial Inputs	Interest Rate	8.0	%	
	Inflation Rate	3.0	%	
Burdened Salaries and Labor Rates	Engineering	111,000	$/yr.	
	Supervision	111,000	$/yr.	
	Operator	25	$/hr.	
	Maintenance	35	$/hr.	
Scheduled Production	Hours/Year	8400	hrs.	
System Prove-In Costs	Engineering Effort	1.4	hrs.	
	Maintenance Effort	1.4	hrs.	
	Operator Effort	1.4	hrs.	
	Materials Consumed	500	$	
	One-Time Opportunity Costs			√
Other	Gas stick capital cost	2,130	$	
	Gas stick expense cost	2,440	$	
	Depreciable Life	5	yrs.	
	Floor Space Rent	20.83	$\$/\text{ft}^2/\text{month}$	
	Floor Space Required	0.125	ft^2	
	Pre-Purchased Inventory of Components			√
	Supplies	3	$	
	Consumable Parts			√

Continued on Page 5

COO Model ... cont. from page 4

Table II. Inputs to the COO Model That Differ with Case.

Category	Parameter	Value	Units	Case
Reliability Availability Maintainability Data	Mean Time Between Failure	17,520 43,800	hrs.	2 yr. MFC life 5 yr. MFC life
	Fab Production Cost per Failure	226 249 301 678 1,281	$/hr.	oxide etch thermal diffusion furnace poly etch tungsten CVD MeV ion implant
System Prove-In Costs	One-Time Opportunity Costs	768 847 1,023 2,305 4,355	$	oxide etch thermal diffusion furnace poly etch tungsten CVD MeV ion implant
Other	Pre-Purchased Inventory of Components	95 38 229 91	$/yr.	2 yr. MFC life, MFC only replaced 5 yr. MFC life, MFC only replaced 2 yr. MFC life, entire gas stick replaced 5 yr. MFC life, entire gas stick replaced
	Consumable Parts	1,058 488 1,220 488	$/yr.	2 yr. MFC life, MFC only replaced 5 yr. MFC life, MFC only replaced 2 yr. MFC life, entire gas stick replaced 5 yr. MFC life, entire gas stick replaced

3. Results

The COO is dissected for one case (tungsten CVD tool, two year MFC life, only the MFC is replaced) to explain the calculations. For other cases, only the total COO over the five year life is presented. Table III shows the cost breakdown for the dissected case. Annual costs sum to give total COO. These break out into fixed, variable, and one-time prove-in costs. Fixed costs are a small percentage of COO (8%), as are one-time prove-in costs (10%). The latter consist mainly of the opportunity cost associated with qualifying the gas box after installation. This cost is probably not realized in most cases since gas box qualification could be done simultaneously with other tool qualifications. Variable cost, about 80%, is the largest component of COO. Two categories account for almost all of the variable cost. These are consumables and cost to production due to system failure. In this model, most of the cost to production due to system failure is the opportunity cost of downtime. Die yield loss, which could be caused by particle shedding from a failed gas box component, would also show up in cost to production. However, this model did not include die yield loss due to lack of data. Production cost alone is 60% of COO, while consumables are 20%. Production cost is a function of response time, repair time, time to run and inspect a test wafer, tool throughput, and value of the wafer at that point in the process.

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COO Model... cont. from page 5

Table III. Itemized Costs for One Case.

This case is for a gas stick on a tungsten CVD process tool in a fab line running 300mm wafers with 250 nm design rule. The MFC life is 2 years.

	Annual Cost, $/yr.				
	Year 1	Year 2	Year 3	Year 4	Year 5
FIXED COSTS					
Depreciation	426	426	426	426	426
Floor space rent	31	32	33	34	35
TOTAL FIXED COSTS	*457*	*458*	*459*	*460*	*461*
VARIABLE COSTS					
Maintenance Supply Costs					
Replacement parts	95	98	101	104	107
Supplies	3	3	3	3	3
Consumables	1,058	1,090	1,122	1,156	1,191
Cost to Production Due to Failure	3,108	3,202	3,298	3,397	3,499
Interest	153	119	85	51	17
TOTAL VARIABLE COSTS	*4,417*	*4,512*	*4,609*	*4,711*	*4,817*
ONE-TIME PROVE-IN COSTS					
Engineering Effort	78	n/a	n/a	n/a	n/a
Maintenance Effort	49	n/a	n/a	n/a	n/a
Operator Effort	35	n/a	n/a	n/a	n/a
Materials Consumed	500	n/a	n/a	n/a	n/a
One-time Opportunity Costs	2,305	n/a	n/a	n/a	n/a
TOTAL ONE-TIME PROVE-IN COSTS	*2,967*	n/a	n/a	n/a	n/a
TOTAL COO	*7,841*	*4,970*	*5,068*	*5,171*	*5,278*

Table IV shows COO for other cases. Note that the COO's are for one stick only, so COO for the gas box would be several times these numbers. As Table IV shows, COO is highly dependent on wafer throughput of the tool. Wafer throughput dictates cost to production due to system failure, all other things being equal, and cost to production is the single largest component of COO.

Table IV. Five Year COO for Various Cases.

All of these cases assume that if the process tool goes down, it impacts total fab production by 0.0053 times the fab output.

Case	Tool Throughput	Five Year COO per Gas Stick	
	wafers/hour	$	$/wafer
MFC Only Replaced			
tungsten CVD, 5 yr. MFC life	90	15,100	0.0040
oxide etch, 2 yr. MFC life	30	16,740	0.0133
thermal diffusion furnace, 2 yr. MFC life	33	17,328	0.0125
poly etch, 2 yr. MFC life	40	18,664	0.0111
tungsten CVD, 2 yr. MFC life	90	28,328	0.0075
MeV ion implant, 2 yr. MFC life	170	43,788	0.0061
Entire Gas Stick Replaced			
tungsten CVD, 2 yr. MFC life	90	29,900	0.0079

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COO Model... cont. from page 6

The results in Tables III and IV and the inputs in Table II assume that the impact on fab throughput of a tool going down is the same for all tools. In reality, this is not true. If the tool that is down is the bottleneck tool, then it impacts fab throughput by 1.0 times its throughput. Otherwise, the factor is less than 1.0. This factor is called the "bottleneck factor." For the results shown in Tables III and IV, the bottleneck factor was 0.0053 for all tools (this number was derived from various discussions with fab factory planners). Results for other bottleneck factors are shown below.

The product of bottleneck factor, wafer throughput, and value of incoming wafer gives the opportunity cost of downtime for the particular tool. With a bottleneck factor of 0.0053 and an incoming wafer value of $1,422, the opportunity costs for the oxide etch, WCVD, and MeV ion implant tools are $226/hr., $678/hr., and $1,281/hr., respectively. The relationship between bottleneck factor and opportunity cost is shown in Fig. 2. As expected, the opportunity cost of downtime for a tool increases with wafer throughput for a given bottleneck factor. The analysis presented in this paper was done using I300I Equipment Performance Metrics [5], which fixes the value of the incoming wafer at $1,422 and hence places the system very far to the left on Fig. 2. In practice, many tools will have a much higher value of incoming wafer and thus a higher opportunity cost of downtime.

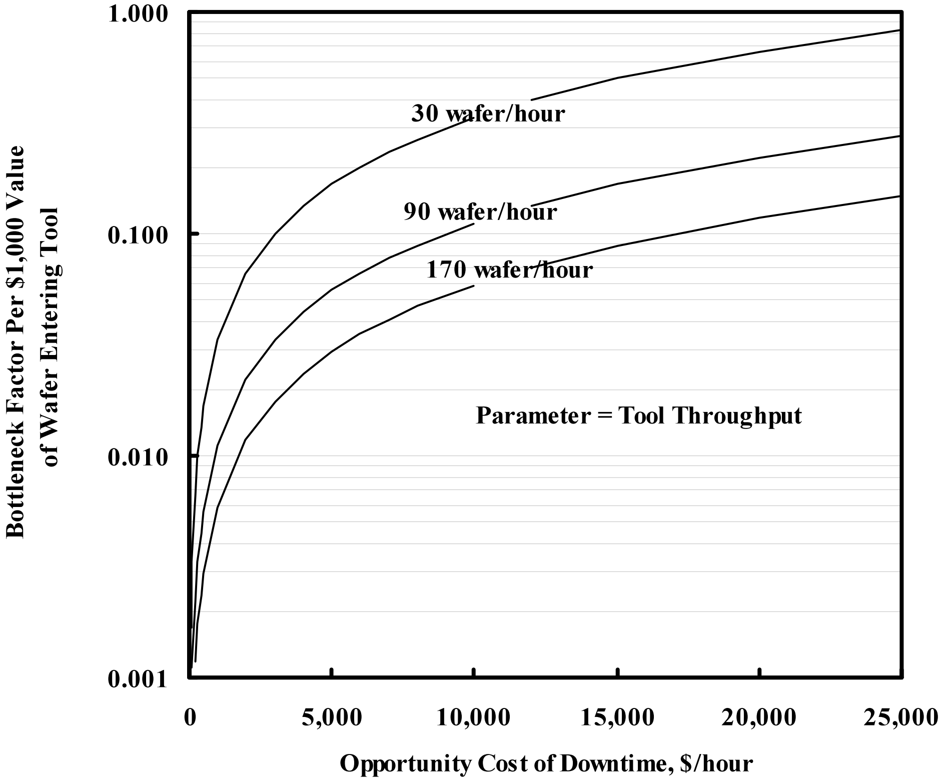

Figure 2. Relationship between bottleneck factor and opportunity cost.

In practice, most fab production personnel do not know the bottleneck factor for a given tool. However, they usually know the opportunity cost of downtime for the tool. To make the model results widely applicable, the calculations were done with a range of opportunity costs. Additionally, the MFC life was made a parameter and varied from 6 months to five years. Figure 3 shows these results. If the opportunity cost of a particular tool is known, then the COO for a given MFC life can be obtained from Fig. 3.

Continued on Page 8

COO Model... cont. from page 7

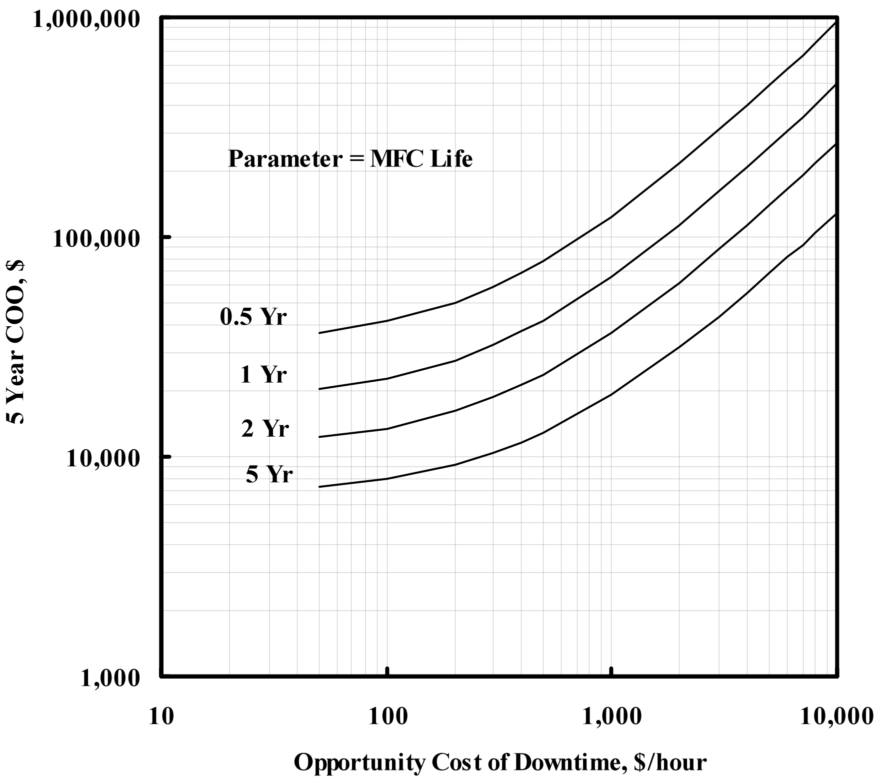

Figure 3. Gas stick COO sensitivity to opportunity cost of downtime and MFC life.

Replacement of the entire gas stick has only an additional COO of $1,572 for any of the two year MFC life cases, regardless of process tool. The COO difference is independent of tool type because replacing the entire gas stick affects only the gas stick cost, and this is independent of the model parameter that differentiates tool types. The COO difference associated with replacing the entire gas stick is even less for a five year MFC life. For this analysis, the difference is $1,014. The rationale behind replacing the entire stick is that, if corrosion causes one component to fail, then there is likely corrosion in other components that has not yet manifested itself. By replacing the entire stick, another failure event is avoided. The model was used to calculate the increase in MTBF needed to give a zero COO difference between replacing only the MFC and replacing the entire stick. For a two-year MFC life, this increase is 1,850 hours, or 77 days.

Conclusions

One can draw several conclusions from this analysis. First, reducing component price has a relatively small impact on COO (a few percentage points), although this impact increases as the component life increases. Hence, manufacturing process improvements and lean production systems that reduce component costs represent incremental improvements. Second, improving component reliability has the most impact on COO. Increasing gas stick life from two to five years has a 200% impact on COO. Third, reducing downtime associated with maintenance can greatly reduce COO (by up to 60%). Ways to reduce downtime include: (1) reduce the time needed to purge after component replacement; (2) provide easier access to the gas box and components in it; (3) standardize component dimensions and interfaces to reduce component installation time; (4) develop new fitting designs that eliminate line twisting problems with existing face seal fittings; and (5) eliminate the test wafer.

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COO Model... cont. from page 8

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6. J. Cestari and M. Yelverton, "Maintaining Ultraclean Gas-System Integrity for Toxic and Hazardous Gases," Tylan General Web Site.

[1] *Trademark Acknowledgments: Elgiloy® is a registered trademark of Elgiloy, Inc.; Hastelloy® is a registered trademark of Haynes Corporation.*

Factory Explorer® v2.5 Released January 15, 1999

WWK is pleased to announce the latest release of Factory Explorer®, its integrated capacity, cost, and simulation analysis tool. Starting with this release, the Factory Explorer analysis engines are available as distinct modules, so you can start with just the modules you need, and add power as you need it! This latest release also includes a variety of useful enhancements, including:

- The new Scheduling Worksheet (output analysis) shows a complete list of all simulated factory events, including lot dispatch. With this worksheet, Factory Explorer® users can perform detailed analysis and planning of lot-by-lot and tool-by-tool factory schedules.
- The new Lots Worksheet (input models) simplifies the process of specifying an initial WIP state for the factory, and of specifying exact lot releases into the factory over time. The companion WIP Snapshot Worksheet (output analysis) provides a detailed list of WIP in the system at the end of each analysis period.
- The new WIP & Cycle Time by Operation Chart (output analysis) allows quick identification of the areas within process flows that contribute most heavily to WIP and cycle time.
- The new Tool Group Setups Worksheet (output analysis) shows detailed setup-related statistics, for use in setup analysis and reduction efforts.
- The Factory Summary Worksheet now displays a variety of on-time completion statistics, including the number of tardy and non-tardy lots, the average tardiness for tardy lots, and the average cycle time for tardy and non-tardy lots.
- New cost-related input parameters and cost-related calculations make it easier to perform sophisticated financial analyses, and to match the results of these analyses against legacy standard-cost systems.
- New input parameters make it easier than ever to model a host of sophisticated factory operations, including setup rules, within-process lot-splitting, and lot routing.
- Enhanced customization interface makes it possible to build your own advanced dispatch rules, and to gather custom output statistics.

Factory Commander™ Version 2.3 Released

Driven by customer response, WWK has released the latest version of Factory Commander™. The v2.3 release contains numerous enhancements and represents yet another milestone in Cost and Resource Evaluation modeling capability. Managers in the IC, FPD, solar panel, disk drive and other electronic component manufacturing industries can quickly and accurately evaluate their strategic and tactical options.

Features added in this release provide an even greater ability to model a wide variety of real-world situations. Some of the key features include user definable depreciation schedules, TWO COOL® database import capability, and a greater flexibility for modeling overhead or non-production costs.

User definable depreciation schedules apply to tool and building capital expenditures. This feature enables a better representation of capital depreciation with regard to government or corporate accounting standards. In addition to straight-line methods, non-linear depreciation methods, such as double-declining balance, can be created and applied to individual equipment groups, the building shell cost, or facility implementation costs.

Data from TWO COOL® (WWK's cost of ownership software) can be imported into Factory Commander™. This routine enables a majority of TWO COOL® cost of ownership model data to be directly ported to Factory Commander™, enabling factory models to be quickly created/updated without manual data conversion or re-input. Data includes tool expenditure and implementation costs, material, consumable & supply usage and costs (based either on annual or per wafer consumption rates), tool availability, floor space usage, tool utility and maintenance costs, and labor groups (operators, maintenance, engineers, and supervisors) and their input quantities.

Overhead and non-production cost categories can now be modeled by one or more of the following cost drivers: Total Cost, Production Cost, Revenue, Headcount, Units Started, Units Outs, and Floor Space. These drivers are independent for each overhead cost category defined.

Some of the other functionality and interface enhancements include…

- ★ Indirect labor groups, such as supervisors or process engineers, can now be assigned to individual equipment groups enabling these labor groups to be modeled as a function of tool system count.
- ★ Maintenance labor can be assigned to individual equipment groups based on downtime and on a shift by shift basis. This enables additional flexibility to model maintenance technicians as a function of a tool's scheduled and unscheduled downtime.
- ★ An alternative method has been added for allocating the factory-level costs (i.e.: building shell, facility implementation and facility operation & maintenance) to the equipment groups based on floor space usage.
- ★ Factory, Building and Sector data can now each be exported from and imported into the program via spreadsheets.
- ★ Dates in Factory Commander™ can be defined in one of seven different formats that conform to the different international standards: American (*mm/dd/yyyy*), ANSI (*yyyy.mm.dd*), British/French (*dd/mm/yyyy*), German (*dd.mm.yyyy*), Italian (*dd-mm-yyyy*), Japan/Taiwan (yyyy/mm/dd), and USA (mm-dd-yyyy).

Factory Commander™ is the best choice for your factory's cost/resource evaluations needs. Let Factory Commander™ reduce the confusion of manufacturing costs and show you the way to increased profitability. For additional information contact Wright Williams & Kelly at 925-485-5711. $

Integrating Targeted Cycle-Time Reduction Into the Capital Planning Process

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ABSTRACT

This paper describes the development and application of an integrated static capacity and dynamic simulation analysis methodology for purchasing equipment capacity. The goal of the study is to address targeted cycle time objectives in a start up Recording Head Wafer manufacturing facility at Seagate Technology, Minneapolis, MN. The short product cycle time, coupled with the competitive nature of the disc drive industry, has made cycle time reduction one of the most important objectives of production capacity planning. This paper describes an equipment procurement strategy in which static capacity analysis is used to identify an initial equipment set with a low slack capacity variable on each tool group. Simulation analysis is then used to identify the critical tool groups that contribute to cycle time delays. The Seagate Industrial Engineering team used the simulation analysis tool Factory Explorer® from Wright Williams & Kelly to perform the cycle time reduction analysis. This targeted approach is compared to the traditional static capacity planning approach of globally applying reserve capacity buffers of 20% or more to achieve the same cycle time reduction goal. Overall, the targeted approach has proven to be efficient in terms of minimizing capital equipment expenditures and also effective on the factory floor.

1. INTRODUCTION

In the competitive semiconductor industry, manufacturers closely monitor their manufacturing performance measures. The foremost performance measure for any semiconductor company is the manufacturing facility's (fab) cycle time. The process studied here is the manufacturing of wafers to make disc drive heads. The reentrant wafer process has more than 400 complex steps across 100 advanced tools with random uptime and processing times. Continuous process improvement and the introduction of new technology have led to shorter product life cycles, while simultaneously making the wafer manufacturing process more complex. Shorter product life cycle times have also made it necessary to reduce the wafer cycle times while maintaining the same level of production capacity. Many benefits may be attributed to reduced cycle times, including shorter learning curves, reduced scrap, and general process improvement (Nemoto *et. al*., 1996. Potti and Mason, 1997). This paper outlines a capacity planning methodology formulated to include cycle time objectives in the capital purchasing procedure, using both simulation and static capacity analysis.

Simple spreadsheets are useful for analyzing capacity quickly. However, they cannot accurately assess cycle time repercussions. Another modeling approach is that of analytical queuing network models (AQNM). These models can provide quick estimates of steady state results regarding total system output and average resource utilization. They can be invaluable in making fast turn around decisions and in screening alternative scenarios. Another benefit to AQNM models is that they require a relatively small number of data inputs. However, some drawbacks exist. Unlike simulation models, which provide transient state results, AQNM models usually analyze the system under "steady state" conditions. They also generally require limiting assumptions about the system characteristics like rework, reentrant flow (multiple visits to the same tool group), and non-exponential random failures. Such dynamic and detailed analysis requires the use of discrete event simulation. Therefore, this paper does not discuss AQNM models further. Interested readers are referred to research papers by Suri and Diehl (1988) and Suri *et. al*., (1993) for more information.

In most static capacity models, excess capacity of 10% to 30% is maintained across all equipment groups to fulfill cycle time objectives. This "brute force procedure" of installing excess buffer capacity at all the tool groups is in practice a very costly method of ensuring low cycle times. A more cost-effective method is to first plan a tool set with a smaller buffer of slack capacity across all equipment groups, and then purchase high cycle time contribution tools to reduce overall fab cycle time. This method does not guarantee a mathematically "optimal" cycle time (best cycle time for lowest cost). For Seagate, however, it has rendered an acceptable cycle time at a much

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lower cost than the less efficient approach of maintaining a large global slack capacity variable across all the tools.

Seagate made their latest expansion of the wafer manufacturing facility at Minneapolis, MN by commissioning a new fab. One of the key objectives assigned to the Industrial Engineering capacity planning group was to develop an organized approach for benchmarking the new fab cycle time and purchasing equipment capacity to meet the cycle time objectives. Seagate hired Wright Williams & Kelly (WWK) to assist the Industrial Engineering team in this effort. The analysis tool was WWK's modeling package. Factory Explorer® (FX®) is an integrated software package, capable of cost modeling, capacity analysis, and detailed factory simulation. FX® uses an Excel® spreadsheet as the front end for loading data and setting model parameters. This integration with Excel® allows users to exploit Excel®'s data manipulation features when storing data. Furthermore, it reduces the model preparation time significantly and simplifies the modeling task, compared with other user interfaces.

Creating a FX® model at Seagate requires loading data into several Excel® worksheets. One worksheet contains the product level information, including, for each product, the product name, start rate, default priority, lot size, release pattern, and process flow name. Another worksheet contains tool group information, including, for each tool group, number of workstations, downtime parameters, dispatch rule, tool capital cost, and minimum and maximum load size. Additional worksheets contain step-level data for each process flow defined in the model. For each step, tool group, processing time, and rework and scrap parameters are defined.

METHODOLOGY

The simulation project was divided into three modeling and analysis phases. Phase I involved collecting model input data, identifying critical system performance measures, and preparing the base model. In Phase II, the model was analyzed in detail by reviewing the output reports. An iterative method was then used in Phase III to assess the equipment capacity and develop an equipment purchase plan that would achieve cycle time goals for various phases of the production ramp.

Phase I

Phase I of the project included data preparation activities such as gathering equipment process times from the time standard database and obtaining engineering process time estimates for new tools. A single process flow (single product) was modeled. Historical equipment downtime data was collected from the maintenance group's equipment resource tracking system. To reduce the complexity of the project, material handling time between the stations was excluded from the analysis. Similarly, operators were not modeled. Inline process yields, rework data, and scrap data were downloaded from the shop floor control system. Setups were minimized through application of a setup avoidance dispatch rule. A smaller wafer lot size was assumed than the typical large size lots used by semiconductor manufacturers. Smaller lot sizes make equipment utilization very sensitive to batch load size. The default dispatch rule was first in first out (FIFO). The equipment loading rule invoked combined lots with the same recipes for processing. The minimum or maximum batch load size were set per rules followed on the production floor at each equipment group. For the random failures, mean time between failures and mean time to repair were modeled using an exponential distribution. Maintenance events were modeled with a constant distribution. Factory shutdowns were not modeled, nor were back-up tools or alternate process paths. Key modeling assumptions are summarized in Table 1.

Maximum tool utilization set at 85% (for base model)
No material handling time modeled
Infinite labor assumed
Single product modeled

Table 1: Key Modeling Assumptions

A base model was prepared with start up equipment bought for the new fab. Base runs were executed at a low start rate to verify the FX® simulation model. The base model output reports were analyzed to assess key system performance measures such as throughput, cycle time and equipment utilization. The fab loading was then set to the minimum anticipated production volume level. The three main performance measures for verification were: equipment count; equipment utilization by category (e.g. offline % and busy %); and product cycle time.

When analyzing capacity, FX® first computes the available capacity for each tool group by downgrading the total scheduled time by unscheduled downtime, maintenance events, setups and repairs. FX® then predicts an estimated capacity loading % value for each tool group that represents the percentage of available capacity at the tool group that is currently being used for production. (Chance, 1997). The suggested tool quantity in

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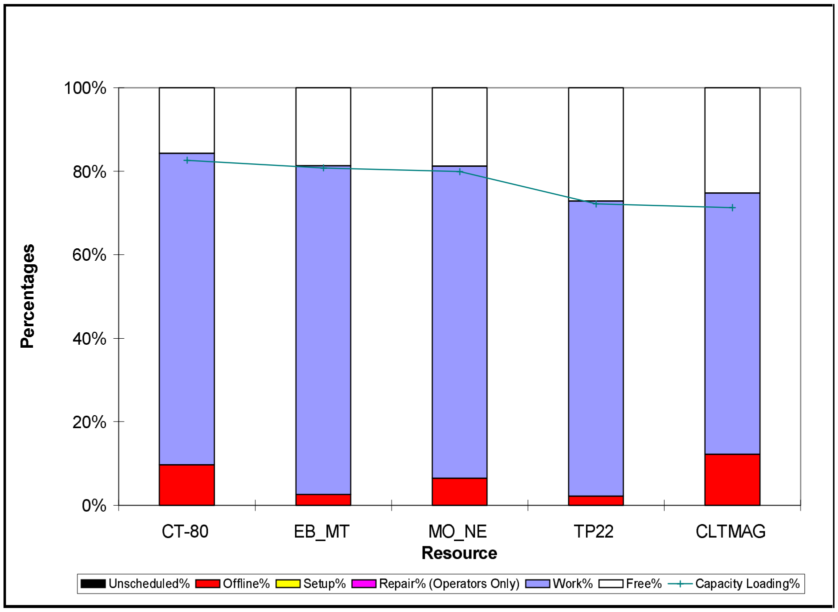

Figure 1: Example of Bottleneck Resource Chart

each group is then determined such that the capacity loading % value for the tool group stays below a user-defined global maximum loading (85% in this case). Percentage capacity loading in this study is considered to be same as equipment utilization. The user can either tell FX® to use the suggested equipment count, or can just use the calculated capacity loading number for comparison purposes. If the suggested quantities are used, the FX® capacity analysis module calculates the resources required to support the wafer schedule, while maintaining a maximum capacity loading of 85% on any tool group. This is very helpful in identifying the resource requirements without needing simulation, and also in avoiding unstable simulation runs. The model can also be loaded with actual tool counts and the pre-simulation capacity analysis used to refine the model.

The base case model was used to generate the tool list for the new fab. The capacity analysis was run and output data such as the bottleneck resource chart were reviewed to identify the capacity constraints. A sample bottleneck chart is shown in Figure 1, and displays the results of the capacity analysis, with top tools ranked by overall capacity loading. This chart illustrates the capacity usage of each tool group, broken down into free time, processing time, and various components of down time. The capacity analysis in general helps in short-listing alternative scenarios for subsequent detailed simulation analysis. This report was also used for model verification by comparing the equipment downtime (Off-line %) estimates against the observed values. The model was further validated and verified by comparing the FX® tool counts against the Seagate's spreadsheet static capacity model estimates and by comparing the model's behavior with actual shop floor data. The global capacity loading factor for all the tools was set at 85%.

The base model capacity analysis was also used to estimate the theoretical cycle time or "Raw process cycle time". Raw process cycle time is defined as the total time it takes to process a wafer lot, independent of queuing times, machine downtimes, rework, yield and other non product value-added times (Chance, 1997). After analyzing the FX® capacity analysis output reports, the base model simulation runs were executed. Key system performance measures tracked were tool utilization, system throughput, mean cycle time and queue delay time at each workstation. The average wafer cycle time predicted by the FX® simulation analysis was compared for verifi-

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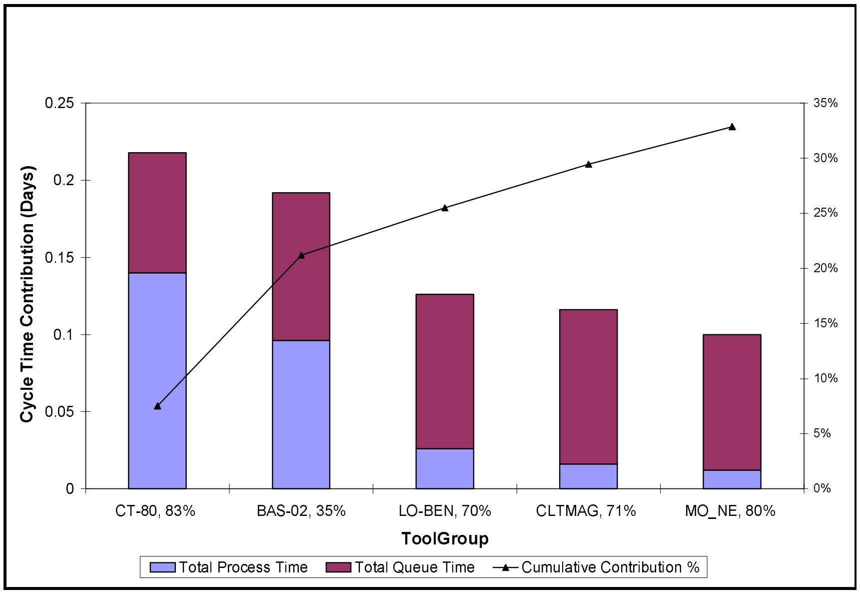

Figure 2: Example of Cycle Time Contribution Chart

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cation against the factory cycle time and throughput data.

The top cycle time equipment contributors were identified by reviewing the FX® report that graphically represents the average time spent in queue and in service at each station. A sample is shown in Figure 2. This report lists the key tool groups that contribute to the product cycle time, ranked in order of cycle time delays. For various reasons, these tools are not always the bottleneck tools in terms of capacity. For example, although tool group BAS-02 is not heavily loaded it still contributes approximately one full day to the total cycle time. Simulation analysis helps to detect such cycle time contributors. This information sometimes leads to low-cost cycle time improvement opportunities. Instead of purchasing additional equipment, batch loading policies and dispatch rules can perhaps be modified to lower cycle time. This type of cycle time and queue size analysis is beyond the realm of pure static capacity analysis. Typically, in a static capacity analysis, the aforementioned tool would have never been suspected of causing cycle time delays because of its excess capacity.

2.2 Phase II

After validation and verification of the base model were completed, the simulation software was used to develop a capital equipment plan for a moderate factory production target. The cycle time target was set between two and three X, where X is the theoretical cycle time of the process. A series of simulation runs were performed for various global equipment capacity loading values. For each value, FX® generated the required minimum equipment set, and then ran the simulation to estimate the corresponding cycle time. Figure 3 shows the total equipment cost and average cycle time for each capacity loading value explored.

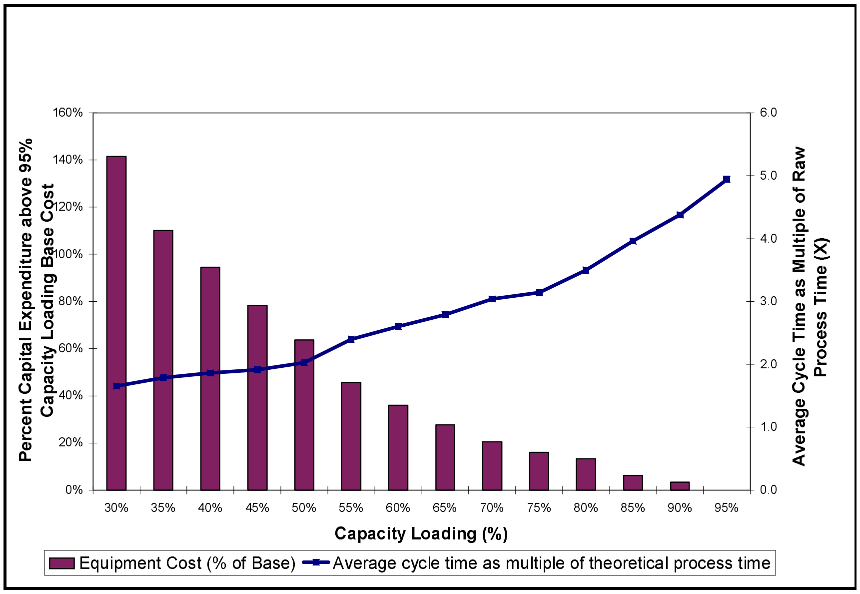

Figure 3: Cycle Time vs. Percent Capital Expenditure above the Base Cost for the Moderate Production Volume Level for Various Capacity Loading Values

Equipment sets with higher capacity loading values (e.g., 90%) have lower total equipment cost but longer cycle times compared to equipment sets planned with lower capacity loading values such as 70%. The main reason for this reduction in cycle time is the addition of more bottleneck servers at lower capacity loading levels. Also, the lower capacity loading equipment sets have fewer one-of-a-kind tools (tool groups containing only a single server). Although the total equipment cost is lower for the higher capacity loading models, the cycle times are significantly longer, especially for factories loaded above 85%. This data was used to illustrate the system behavior and to generate costs for

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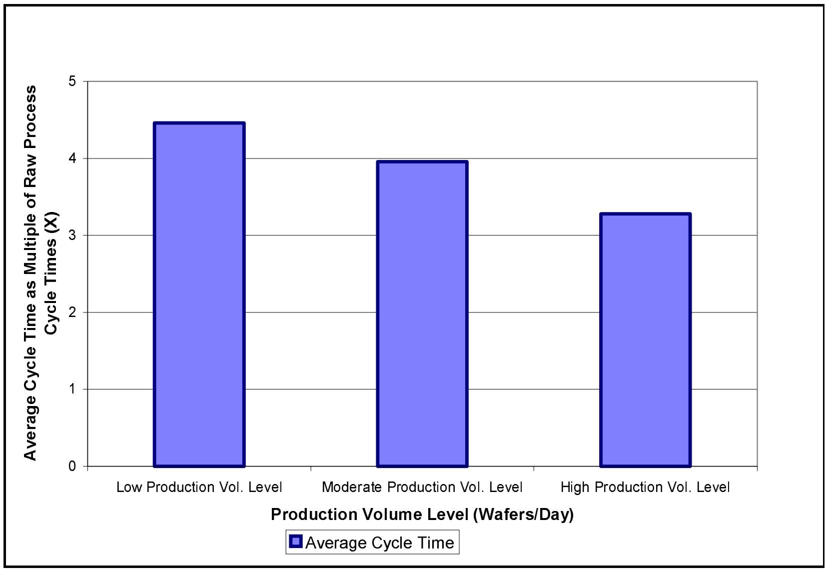

Figure 4: Average Cycle Time Chart for Various Production Volume Levels with 85% Capacity Loading.

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equipment sets with large amounts of slack capacity applied to all tool groups. The latter were used for comparison with equipment sets derived via the informed capacity planning method studied in this paper. Cycle times were also observed to be lower for higher production volume level factories. This effect is shown in Figure 4, which plots the average cycle time against three production volume levels. For each volume level, an equipment set with 85% capacity loading was generated and simulation was run to estimate cycle time.

The next step was targeted cycle time reduction, starting with a high capacity loading factory. WWK, based on their experience in a research project at a leading integrated circuit manufacturer (Fowler et. al., 1997), proposed to use a heuristic optimization method to reach an acceptable solution. This heuristic required multiple analysis passes. For each pass, multiple candidate models were developed and investigated for cycle time reduction (Chance, 1996). The best candidate model became the base model for the subsequent simulation analysis. The specific steps in the analysis are shown below (from Chance, 1996):

Inputs: Production volume level, Capacity loading percentage, Budget Limit $ X Million.

Analysis Procedure:

1. Run Factory Explorer® capacity analysis to create a base model with minimum cost tool set.
2. Run Factory Explorer® simulation to estimate base cycle time and total queue delay time contribution by tool group.
3. For each of the top five tool groups in the base model (ranked by contribution to queue delay):
   a) Starting with current base model, add one tool to the selected tool group to form a candidate model.
   b) Run FX® simulation to estimate the cycle time for the candidate model.
   c) If the new cycle time is statistically significantly lower than the base cycle time, compute the ratio of cycle time reduction to tool fixed cost.
4. For the candidate model with the best (largest) reduction per dollar ratio, record the tool added and replace the base model with the candidate model.
5. Go to Step 3 or terminate (a) if the budget limit is reached or (b) if no candidate model results in a statistically significant reduction in cycle time.

Seagate investigated several different production volume levels, to plan for various points in the production ramp of the factory. Several different initial capacity loading values were also explored, to see how these differed in terms of the final recommended tool set. For each of the plans analyzed, the budget was never exhausted and the heuristic reached a stage when additional tools did not result in any significant reduction of cycle time. All simulations were run for two years, with a warm up period of six months to clear model statistics and minimize initialization bias.

Phase III

The chart in Figure 5 depicts the results of the cycle time optimization heuristic performed for the moderate production volume level. The analysis was also conducted for low and high production volume levels. For all levels, cycle time and total tool expenditure were measured for initial capacity loading values of both 70% and 85%.

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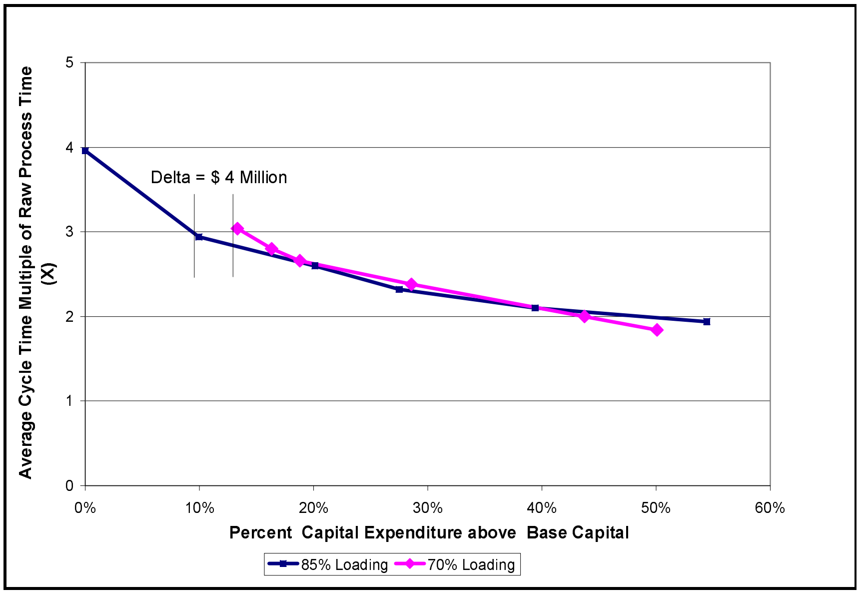

Figure 5: Cycle Time vs. Percent Capital Expenditure above the Base Capital for Moderate Production Volume Level with 70% and 85% Initial Loading

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Key findings from this analysis are summarized below:

- The equipment set generated by starting with a global 85% capacity loading resulted in reasonable cycle times for all the production volume levels analyzed. This cycle time could be improved by purchasing additional high cycle time contribution tools, as shown in Figure 5.

- To achieve the average cycle time objective of 3X days, total equipment cost analysis was performed by using the two approaches, the aforementioned heuristic approach and the "brute force method" i.e., maintaining large slack variable across all the tools. When the analysis was run with a 70% capacity loading, the first iteration (with no extra tools) resulted in a total tool cost of $ 75.6 Million with an average cycle time of 3X days. When starting with an 85% capacity loading and purchasing cycle time contributing tools a similar cycle time was achieved at a much lower cost of $ 71.5 Million – a net saving of nearly $4 Million, as shown in Figure 5.

- Regardless of which initial capacity loading number is used, this study shows that using the analysis procedure described in the previous section leads to a much more cost effective tool set than does a "brute force" approach of creating large slack capacity across all tool groups. To achieve an average cycle time of 2X days using the simulation procedure described above costs $ 9 Million less than it would cost to reach 2X days by the "brute force" method. This is because cycle time does not drop to 2X until the suggested loading is as low as 45% when globally applied (Figure 3). Overall, the most cost effective informed strategy is planning a minimal equipment tool set with a high capacity loading factor and then lowering the cycle time by selectively purchasing additional capacity.

- The graph in Figure 5 also shows the cycle time reduction achieved by adding more tools. The smooth slope gradient represents the achievement of a cycle time limit beyond which the addition of more tools would not statistically reduce the cycle time. A substantial amount of capital would have to be spent to attain significant cycle time reduction beyond 2X days.

3. CONCLUSION AND RECOMMENDATIONS

This project provided Seagate management with the information needed to purchase cost-effective equipment sets that could achieve cycle time objectives at various production volume levels. The analysis was also helpful in establishing the theoretical wafer cycle time benchmark and in predicting the average wafer cycle time. More experiments could be done to show cost savings by planning capacity at a higher capacity loading factor (e.g. 90% or 95%) and then purchasing additional equipment to reduce the cycle time. The scope of the project could also be expanded to perform more detailed analysis by including additional factors such as labor constraints and hot lots. This combined capacity and simulation analysis technique, targeted at high cycle time contribution tools, saved Seagate a significant amount of money by recommending the purchase of fewer tools than would have been needed by applying more slack capacity across all tools.

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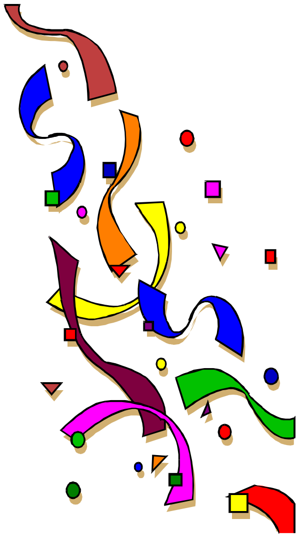

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