APPLIED Co$t MODELING

Information Exchange For Your Application & Use of Cost Modeling

Volume 10. Issue 1

Inside

Fall 2003

ISSN 1094-9739

Welcome Back

It is with great pleasure that we welcome back all of our loyal readers. Applied Cost Modeling has been dormant for the past two years but it was never out of our minds; hence our decision to keep our volume and issue numbers in line with what they would have been. Since its humble beginnings in the back of an insurance agency in Sacramento, we have always strived to provide content of technical and strategic value to our readership.

As most of you are now aware, the management team at WWK has reacquired the company and we look forward to putting back in place those valued pieces that you had come to expect from us. That doesn't mean we are living in the past; quite the contrary, we look forward to a high rate of change and innovation. We aim to make ACM once again a platform to inform you of the latest advancements in modeling and simulation.

As always, comments and submissions are greatly appreciated.

The Employee Owners of WWK

Editorial Board

Publisher

Published quarterly by:

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Calendar of Events

December

3-5 **SEMICON Japan**
Tokyo, Japan

January

11-14 **Industry Strategy Symposium (ISS)**
Pebble Beach, CA

February

18-20 **SEMICON Korea**
Seoul, Korea

March

17-19 **SEMICON China**
Shanghai, China

April

19-23 **SEMICON Europa**
Munich, Germany

May

4-6 **ASMC**
Boston, MA

June

9-12 **SEMI FPD Expo Taiwan**
Taipei, Taiwan

July

12-16 **SEMICON West**
San Francisco & San Jose, CA

TBD **How to Successfully Manage New Product Introductions – SEMICON West**

TBD **Understanding and Using Cost of Ownership – SEMICON West**

Cost-of-Ownership as a Real-time Control Metric

Howard Ignatius, EGsoft, A Division of Electroglas, Inc., San Jose, California

Daren Dance, Wright Williams & Kelly, Pleasanton, California

The key to success for a chip manufacturer running 300-mm silicon is overall fab efficiency (OFE), an extension of the traditional concept of overall equipment efficiency (OEE). OEE, in turn, is a sub-set of Cost-of-Ownership (CoO). CoO parameters, such as tool throughput and utilization, determine manufacturing efficiency. But traditional manual data collection has limitations; the frequency of new data points can be insufficient to drive real-time decision processes. Traditional, data collection techniques are inappropriate for continuous process improvement. If CoO data is gathered in real time, it becomes a dynamic basis for decision making. Not only can it identify why a "bad" tool is bad, but it can determine why the "good" tool is better. The use of dynamic, real-time CoO can be the fast track to optimized OEE.

The inputs to CoO calculations (Figure 1) such as tool throughput and utilization are the same parameters, which on a fab scale, determine manufacturing efficiency. Combined with statistical process control (SPC) methods, dynamic CoO can be used to:

- Monitor and continuously update assumptions,
- Report progress toward cost control,
- Optimize the process based on best-known ROI rather than theoretical ROI,
- Make informed cost-reduction changes, and
- Convert simulations and forecasts into measurable process control tools.

$$CoO = \frac{F + R + Y}{L \cdot T \cdot CY \cdot U}$$

F = Fixed Costs
R = Recurring Costs
Y = Yield Costs

L = Tool Life
T = Throughput
CY = Composite Yield
U = Utilization

Fig. 1: Example cost of ownership parameters

<u>Real-time CoO</u>
Using real-time CoO, a change in an input parameter can be evaluated in terms of its effect on the components of CoO. Figure 2 illustrates the concept using Training as a variable. If more money is invested in the training of maintenance and operating personnel, the real-time CoO will reflect this in other cost metrics such as is equipment availability (improved uptime), labor (more efficient operation), and maintenance (lower MTTR).

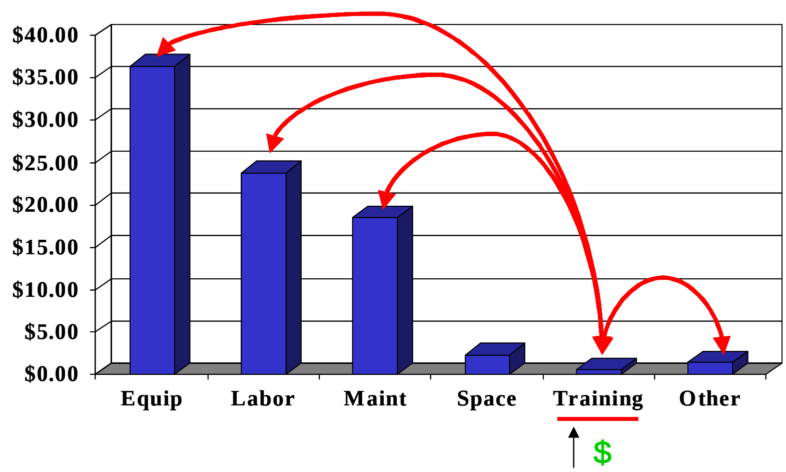

Fig. 2: "What if" CoO analysis

To illustrate the use and benefits of real-time CoO we examine examples from two very different processes, wafer sort and tungsten chemical vapor deposition (CVD). The concept can be extended to any tool that

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conforms to the SEMI E-10 Guideline (Definition and Measurement of Equipment Reliability, Availability, and Maintainability), as well to any combination of fab tools such as a work cell.

Wafer Sort

As devices have become more complex, the cost of wafer probe test has increased significantly. Test pads have shrunk to accommodate higher pin counts so probe alignment is more demanding. The control of test parameters becomes more critical as voltage and current decreases. Temperature has become a significant test parameter. Over the recent past, probe card costs have increased ten times, probe stations have doubled in cost, and test systems have gone up 5-10 times. For these reasons real-time CoO during prober operation is a welcome tool for cost control.

The configuration for real-time CoO data collection and communication is illustrated in Figure 3. Each test probe station (left side) is connected by a two-way communications link to a central server. The server, in turn, connects to the corporate intranet and can also be linked outside the site to via a secure Internet connection. Data and reports can be accessed internally and external via standard web browser software. Customized reports are generated from the prober data and can be sent via intranet connections to users within the company. Proprietary yield data is blocked from the Internet by server software– only tool-related information can be sent outside the enterprise. An open data acquisition format allows data to be accessed from any open database compliant (ODBC) test stations. The data from the test floor can include reports on the equipment state, wafer yield maps, and bin monitoring.

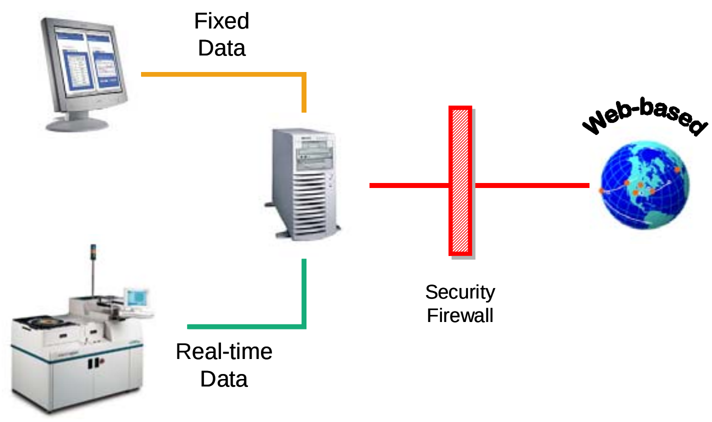

Fig. 3: Wafer test data collection and distribution

The interrelation of process variables and fixed costs is shown in Figure 4 as a logical summation process. Variables feed into a logical NOR operation (purple) and then together with fixed cost data (capital, facilities, consumables, etc.) feed into a logical AND operation (green). The web-based output appears on the computer display such as shown in Figure 5.

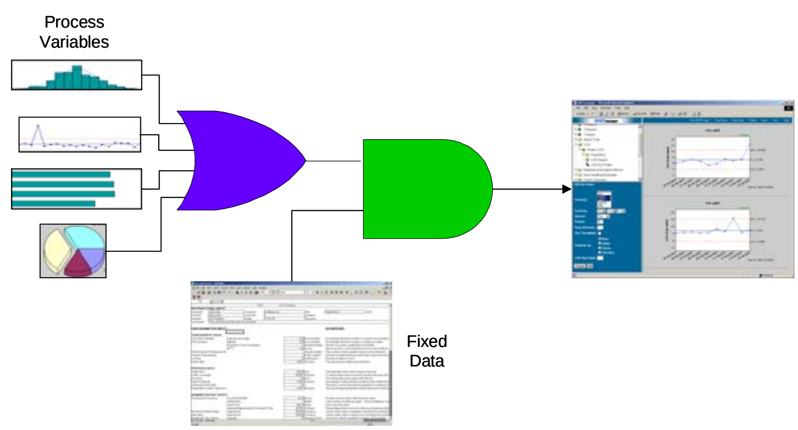

Fig. 4: The logical sum of all process variables in terms of cost

[Continued on Page 6]

Management Team Acquires Wright Williams & Kelly

September 18, 2003 (Pleasanton, CA) – A team led by current senior management and original co-founders of Wright Williams & Kelly (WWK) announced today it has acquired the assets of the company. WWK was founded in 1991 and, since 1995, was operated as a subsidiary of CH2M Hill Industrial Design & Construction (IDC), the semiconductor industry's leading engineering services provider.

Daren Dance, WWK's VP of Technology and SEMI Metrics Committee Chairman, stated that all customer and technical support resources have been integrated into the new organization. "There will be no interruption in operations, customer service, or technical support. Our clients have been, and will remain, our top priority including meeting requests for permanent, on-site resources."

"The acquisition team is excited about implementing our strategic vision," stated David Jimenez, WWK co-founder and President. "With a full complement of highly qualified human resources and the financial backing provided by a significant over-subscription to our private placement, our customers can expect to see substantial enhancements to our software product line and support services in the immediate future."

WWK is a vital industry resource as its productivity and cost management tools are powerful antidotes to the effects of deflation and the lack of product pricing power. And, in the midst of pervasive overcapacity, WWK's tools can rationalize capital allocation.

Today's key challenge for semiconductor manufacturers is to sell the output of their leading-edge fabs. Not many have control of enough high volume chip markets to run a leading-edge fab at peak production. WWK can help to efficiently match process capacity/technology with expected sales volume.

Additionally, non-300mm fabs are facing strategic milestones regarding upgrades, going fabless, consolidation, or niche applications. These involve significant capital decisions and WWK's tools and consultants can assist in making these decisions efficient and effective.

With more than 2,800 users worldwide, Wright Williams & Kelly, Inc. is the largest privately held operational cost management software company serving technology-dependent and technology-driven companies. WWK maintains long-term relationships with prominent industry resources including International SEMATECH, SELETE, Semiconductor Equipment and Materials International (SEMI), and national labs and universities. Its client base includes most of the top 10 semiconductor manufacturers and equipment and materials suppliers as well as leaders in thin film record heads, magnetic media, flat panel displays, and solar panels.

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Continued from page 4-Real Time COO

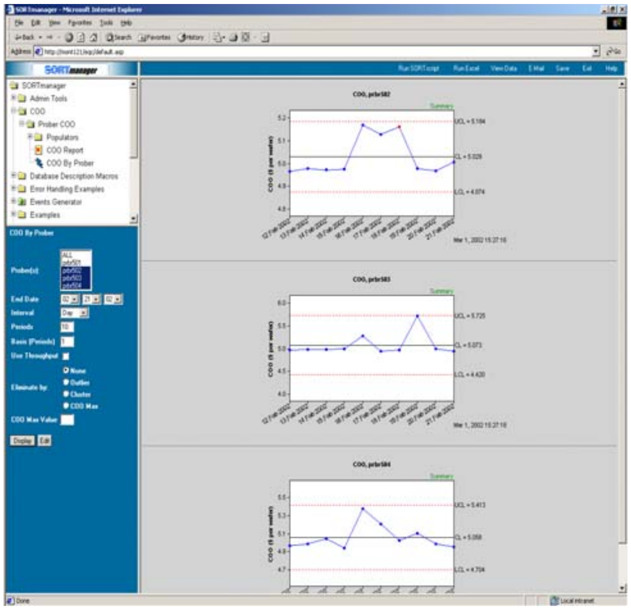


Fig. 5: Screen shot of daily wafer probe data

Figure 5 is an example of real wafer sort data for three Electroglas probe stations in the form of 10-day SPC charts. Other time intervals could be selected, or, to gain detailed insight, wafer-by-wafer data (cost/wafer) could be tracked. Instead of traditional yield data, such as average number of good die per wafer, the parameter plotted is 'COO,' which is derived from a modified version of the CoO formula (Figure 1) that includes real-time tool parameters. In the example of Figure 5, each point represents the COO for one day. Note that control limits differ from station to station; control limits are calculated by collecting data from a statistically significant number of wafers for the specific probe station. This makes it easy to determine which probers are operating at less than optimal efficiency. Violations of user-selected SPC rules are flagged as red data points.

Figure 6 shows real wafer sort data for 22 days from each of two probe stations. The bottom chart shows rule violations for days 13 and 14 (more than seven points below the center line) and for the last day (one point above the upper control limit).

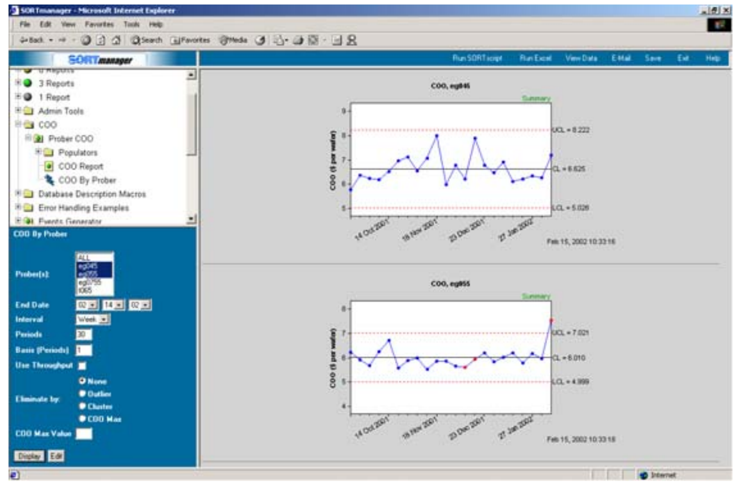


Fig. 6: Screen shot of daily wafer probe data

Figure 7 shows how details of an SPC rule violation can be displayed for three probe stations. Wafer sort data are displayed for a sequence of ten days of data from a single probe station. Each point represents the average of all the data from one day. The data for the first and last days have been removed for a special (known) cause and the CoO value for those days is displayed. The inset (TIP) shows the details from the date (Jan 11) selected by the cursor. In this case it displays the specific SPC rule that was violated.

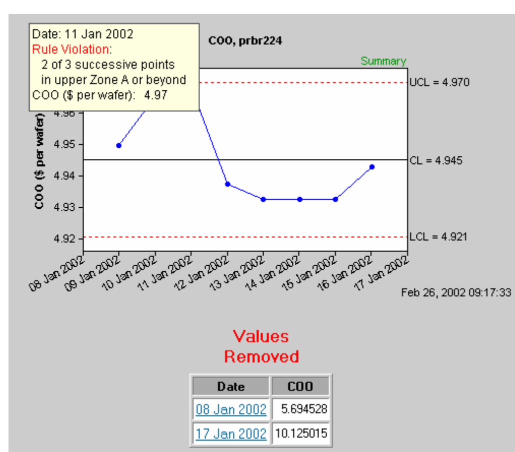


Fig. 7: Details of an SPC rule violation

Tungsten CVD

The advantages of combining CoO and SPC allows one to continuously monitor and update CoO assumptions. Simulations and forecasts can be converted to measurable process control tools. Process changes can be implemented and the results immediately available that measure the progress towards cost containment goals. The process is optimized based on the best possible rather than the projected return on investment. Process decisions that reduce costs can be validated with timely, continuous data analysis.

Table 1 and Figure 8 show the results from the optimization of a SEMATECH tungsten CVD process. The expected cost per wafer was about $13. The actual average CoO was an unacceptable $21 per wafer and varied widely. The best CoO was about $6 showing that the process could, when in control, exceed expectations. This gave an incentive to attempt process optimization. The optimization steps included adding a pre-pump down purge, increasing pump down time, and monitoring the chamber pressure after the plasma clean step. Although the first two changes may have projected to decrease wafer throughput, the positive changes in other parameters included in the CoO outweighed this effect. Without a CoO analysis it might have been more difficult to justify a change that might impact throughput. The final average CoO equaled the best CoO obtained prior to the process changes and the variability was significantly lower. Continuous CoO monitoring should aid in further reducing the variability.

Figure 8 shows a trend chart of CoO for the tungsten CVD tool. There is a significant improvement in both the value and variation of the CoO after the listed process changes were made.

Summary

Traditional static CoO analyses help in making purchase decisions, but require more frequent data collection for process control. When real-time data is used to calculate CoO and the result is analyzed with proven SPC techniques, you have a tool to dynamically monitor and control the cost of a process. Cost-focused SPC provides a metric of the process and "bottom line" effects when making changes to improve profitability.

Expected CoO	**$13.24 per wafer**
Actual average CoO	$21.11 per wafer
Highest CoO	$71.84 per wafer
Best CoO before change	$5.73 per wafer
Process Changes:	
Pre pump-down gas purge	
Extended pump-down	
Monitor post-etch chamber pressure	
Average CoO after change	**$5.73 per wafer**

Table 1. Tungsten deposition process optimization using CoO

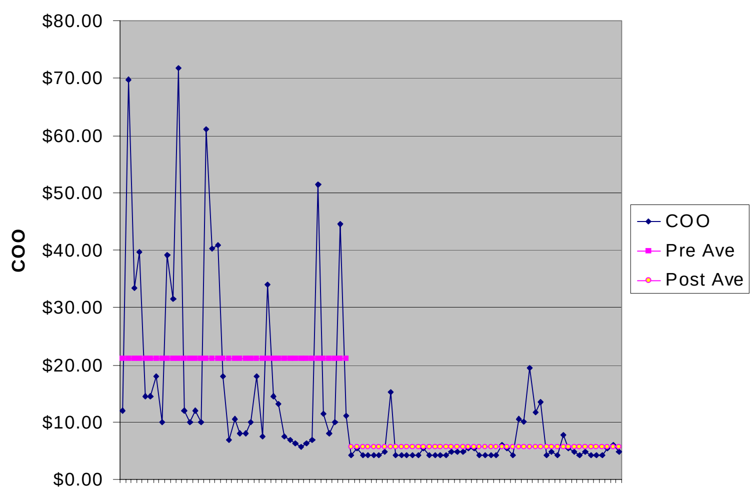


Fig. 8: Trend chart of CoO for tungsten CVD process before and after process optimization based on CoO analysis.

The advantages of real-time CoO echo those of traditional statistical process control employing process parameters. The earlier a cost issue is identified, the fewer wafers will be impacted, the less processing time wasted, and the lower the cost. In wafer fab the value of each wafer is staggering. In wafer test the cost of shipping potentially faulty units can be extremely high. With real-time CoO monitoring the results may be fed back to create a value-added step.◄

Is There Life in 200mm?

Daren L. Dance
Wright Williams & Kelly, Inc

For the last five years or more, 300mm wafers have been the big news for semiconductor manufacturers. But what if you don't have the $1 – $3 billion that building a 300mm fab may cost? Is there still life for 200mm wafer fabs? Of Course!

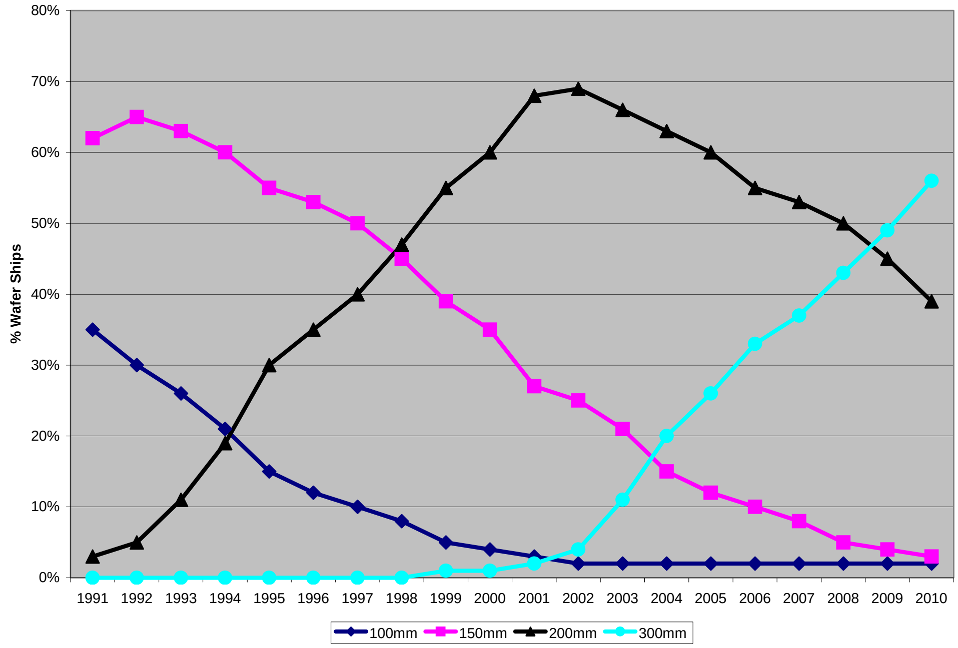


Figure 1: Semiconductor Wafer Size Transitions[1]

Figure 1 shows historical and forecast wafer size trends for semiconductor fabrication. While 2002 will probably be the peak of 200mm wafer usage on a percentage basis, actual usage of 200mm will continue to increase (although at a slower rate than 300mm). One forecast[2] projects that 469 million square inches more 200mm silicon will be used in 2006 than were used in 2001. In fact, if the rate of decline of the usage of 150mm wafers in Figure 1 were extrapolated to 200mm; 200mm wafers will still account for at least 20% of wafer fabrication in 2013. Yes! There is still life remaining in 200mm wafer fabrication.

Conventional Wisdom

Conventional wisdom has the semiconductor industry focusing on 300mm wafers as the wave of the future. Prior wafer size transitions, as depicted in Figure 1, have been driven by increased

[1] Years 1991-2001, Semico Research Corp., as quoted by D. Vogler, "Evolving Business Strategies Are Key to an Upbeat 300mm Outlook," Solid State Technology, October 2002, p. 27.
Years 2002 – 2010, WWK Forecast.
[2] Rose Associates/IC Insights, Inc., as quoted by D. Vogler, "Evolving Business Strategies Are Key to an Upbeat 300mm Outlook," Solid State Technology, October 2002, p. 27.

device area, particularly for memory devices. Larger wafers have a larger effective area available for larger devices – thus larger wafers have higher productivity. This is illustrated in Figure 2.

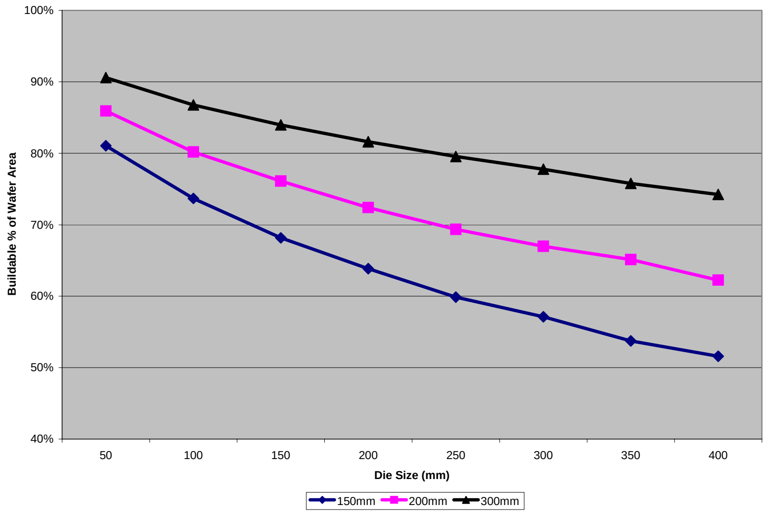


Figure 2: Effective Area by Device and Wafer Size[3]

In addition to better area efficiencies, larger wafers also produce more die for the same number of processing steps. Depending on device area, a 300mm wafer produces 2.2 to 2.7 times more testable die per wafer than a 200mm wafer. Thus, manufacturing large complex circuits, such as microprocessors, on 300mm wafers can achieve significant cost-per-die production savings. It should be no surprise then that Intel is among the leading companies integrating 300mm wafer fabrication.

Memory IC manufacturers have large production volumes and lower profit margins. These should also benefit from 300mm manufacturing. Foundries should also significantly benefit from 300mm wafer fabrication as they aggregate orders from many sources. These can be combined to provide the volume on which the 300mm economies of scale depend. Announced plans for 300mm wafer fabs are summarized in Table 1.

Table 1: Planned 300mm Fabs[4]

Production Type	Fabs Planned
Memory	7
Foundry	6
MPU/DSP/Logic	4

Note: Production Fabs only – excludes pilot lines and R&D.

As expected, memory and foundry fabs lead the interest in 300mm manufacturing.

Comparing 200mm and 300mm

In our popular training class, WWK cautions users of cost of ownership, "Equipment specifications must represent actual performance under the process conditions . . . and not just paper specifications."[5] Many comparisons of 200mm fabrication with 300mm fabrication do not pay attention to this requirement. Instead, actual 200mm fabrication is compared against a theoretical 300mm manufacturing model that was published in 1997, before significant 300mm manufacturing experience had been accumulated[6]. Many of the assumptions used in this study have been perpetuated, even when actual performance experiences differ. Table 2 summarizes some critical assumptions from the 1997 study and the adjustments made to better reflect current manufacturing experience and economics.

WWK expects that these adjustments to the basic assumptions will allow the simulation to more accurately reflect 2002 operating conditions for both 200mm and 300mm integrated circuit manufacturing

A Factory Commander® cost simulation of 200mm and 300mm show the results summarized in Table 3. Using the assumptions from Table 2 and comparing identical processes,

[3] Assumes 3mm edge exclusion for all wafer sizes.

[4] Strategic Marketing Associates, October 2002.
[5] "Understanding and Using Cost of Ownership," Wright Williams & Kelly, 2002, p. 4-2.
[6] "Tool Performance Requirements and Cost Sensitivity Analysis for 180nm/300mm Aluminum and Copper Interconnect with I300I Tool Performance Metrics, 31 January 1997. (Note – SEMATECH Confidentiality restrictions on this document expired 31 January 2001.)

these simulations show that the cost of the die from a 200mm wafer is 28% lower than the cost of a die from the 300mm wafer

Table 2: Assumptions

Factor	1997 300mm assumption	Adjusted assumption	Comments
Lithography technology	248nm	248nm (no change)	248nm technology life has been significantly extended
Equipment cost	1.3X 200mm	1.8X	
Equipment footprint	1.3X 200mm	1.5X	While many tools achieved 1.3X it is at the cost of higher ceiling height requirements
Expose throughput	34 wafers per hour	60 wafers per hour	
Die size	385 sq mm	170 sq mm[7]	Increases testable die per 300mm wafer from 132 to 331
Die demand	Full capacity	Fixed capacity	Same die production as 200mm plant with 20,000 wafer starts per month (2.6 million die per month)
300mm Wafer Cost	\$600 / \$500	\$500 / \$300	Prime wafer / Test wafer
200mm Wafer Cost	\$200 / \$120	\$70 / \$40	Prime wafer / Test wafer
300mm materials cost	150%	220%	Percent of wafer cost[8]
200mm materials cost	250%	250%	Percent of wafer cost
Material Handling System (AMHS)	None	\$65 million system cost	Many claim that 300mm requires AMHS[9]

Table 3: 200mm Vs 300mm Cost Simulation Results

Cost Category	Cost / Die 200mm	Cost / Die 300mm	% Change from 200mm	Comments
Equipment Depreciation	\$2.58	2.69	+ 4%	
Building Depreciation	0.29	0.20	- 31%	
Equipment O&M[10]	1.52	0.75	- 51%	300mm O&M cost may be underestimated
Building O&M	0.44	0.30	- 32%	
Labor	0.00	0.00		Not included in this analysis
Wafer Costs	0.56	1.60	+ 186%	Starting wafers and test wafers
Process Materials	1.32	3.79	+187%	2.5X starting wafer cost
Total Cost per Die	\$6.71	\$9.33	+ 28%	
Total Cost per Wafer	\$885.68	\$3,086.81		

[7] International Technology Roadmap for Semiconductors, 2001 update.
[8] The 1997 study assumed that process material costs would remain flat at 200mm rates, however, the consumption of many of the more expensive materials, such as photoresist and CMP materials, increases with wafer area so WWK has assumed a constant multiplier (2.5) rather than a flat rate.
[9] See: Saloni Merchant and Allan D. Chasey, "Impact of AMHS on Design and Construction of 300mm Fabs," Del E. Webb School of Construction, Arizona State University, www.fabtech.org/features/Del.E.Webb/Index.shtml
[10] O&M – Operations and Maintenance. Excludes direct operations labor.

The analysis in Table 3 assumes that both 200mm and 300mm equipment are within a normal 5-year straight-line depreciation timeframe. If most of the production equipment is fully depreciated, as is the case with many 200mm fabs, the cost per die difference is even more substantial as equipment depreciation costs account for 38% of the 200mm cost per die.

Thus, not only is there still life in 200mm wafer fabrication, in many cases there are cost benefits for continuing with 200mm manufacturing.

How WWK Can Help

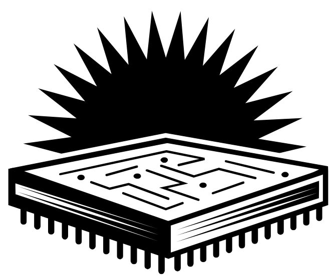
While this analysis clearly shows the 200mm wafer fabrication results in a lower cost per die using the assumptions of Table 2, it should also be clear that there are manufacturing assumptions for which 300mm wafer manufacturing may yield a lower die cost.

Strategic decisions relating to 200mm or 300mm manufacturing are so important that each decision must be analyzed on a case-by-case basis. Some of the factors that WWK would include in a custom analysis include:

- Current fabrication capabilities and costs
- Expected 300mm fabrication requirements and costs
- Product demand
- Technology roadmap

For further information on 200mm vs. 300mm cost analysis, please contact WWK:

Phone: 925-399-6246
Email: info@wwk.com
Web: www.wwk.com



WWK Names First Member to Advisory Board

Announces Formation of Cross-Industry Strategic Planning Council

Wright Williams & Kelly, Inc. (WWK) announced the formation of a multi-industry advisory board to assist the company in broadening the market focus of its cost and productivity management software tools and consulting services. More importantly, they further announced the appointment of the CEO of a major consumer packaged goods manufacturer to the advisory board.

"The formation of our new advisory board in combination with our aggressive use of outside directors is going to be a major advantage in executing our strategic vision for diversification," stated David Jimenez, WWK's President. "The semiconductor and related industries have been the beneficiary of our work over the past decade; now is the time to migrate our expertise to the rest of the manufacturing and assembly industries, regardless of end product or geographic location."

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Wright Williams & Kelly Names Bellwether Technologies Sales Agent

Wright Williams & Kelly (WWK), a cost & productivity management software and consulting services company, announced the naming of Bellwether Technologies, LLC as its sales agent covering the Southeastern US. This appointment represents another step in WWK's strategic vision to provide increased sales and service support in close proximity to all of its customers, world-wide.

"Bellwether was selected to support our critical installed base in the Southeast," stated David W. Jimenez, WWK's President. "They combine a unique understanding of the compound semiconductor industry and the application of our software products and services to drive manufacturing optimization. We look forward to adding them to our team of respected industry experts."

"We are pleased to begin representing WWK," says Taylor Cantrell, President of Bellwether. "We see a large demand for software tools and consulting services designed to help optimize manufacturing costs and productivity. WWK will help keep our clients at the forefront of cost competitive operations."

Bellwether Technologies was founded in 2001 and is a supplier of equipment, materials and services to the semiconductor industry in the Southeast. Located in Columbia, SC, Bellwether is strategically and geographically positioned to assist both the emerging and established semiconductor companies in the region to improve operational efficiencies.

WWK Forms New Division

Primed to Expand Consulting Network

Wright Williams & Kelly (WWK), a cost & productivity management software and consulting services company, announced the formation of a new division, WWK Consulting. This new division brings together a broad-based cooperative of independent consultants operating under consistent project management leadership and with access to WWK's state-of-the-art software tools.

"Since 1991, we have successfully used our software, developed with International SEMATECH and Sandia National Labs, to help companies in the semiconductor and other high-tech industries identify and control manufacturing costs. However, many other businesses have similar cost management issues. By expanding our network of independent consultants, WWK can help these companies with strategic cost analysis and management," stated Daren Dance, WWK's Vice President. "Imagine having the power of skilled consultants at your fingertips to help you identify areas for improvement and to develop creative solutions; Consultants who have weathered the economic ups and downs of their industries."