Information Exchange for Your Application & Use of Cost Modeling

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# APPLIED Co$t MODELING

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## Inside



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## Mask Defect Inspection Strategies: Cost of Ownership Impacts on 193nm Litho Clusters

With this edition of Applied Cost Modeling, we are publishing the second installment in a series on mask defect inspection strategies. Those interested in the cost of ownership (COO) data files behind this study, or the entire report, can find more information under the Special Reports link at:

http://www.wwk.com/products.html

**Direct Mask Inspection Cost Validation**

The base model for litho cluster COO based on direct mask inspection used a cost per inspection of $632. This data point was taken directly from the paper by Bhattacharyya et al. WWK has attempted to validate this number by building a COO model of the direct mask inspection process. Table 3 indicates the assumptions used in building this model.

Report 2 shows the COO results for the assumptions previously listed. The calculated cost per mask inspection is approximately 23% low. Given that inspection equipment have minimal materials usage, the 23% underestimation must be from overestimating system throughput or system availability. It should be noted that if the inspection system is not used for other inspection purposes, the loading will only be 80 masks per week and the associated costs per mask inspection will rise to $858.85. This single change moves the litho cell COO to $54.32. Charts 4 and 5 examine at what point system throughput and availability create the $632 cost per mask inspection.

[Continued on page 3]

# Publisher


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# Calendar of Events

## June 2011

**8-10** **Intersolar Europe**
**New Trade Fair Centre**
**Munich, Germany**

## July 2011

**14** **Understanding and Using COO**
**SEMICON West/Intersolar**
**San Francisco, CA**

## August 2011

**10-12** **Renewable Energy India**
**Pragati Maidan**
**Dehli, India**

## September 2011

**5-9** **EU Photovoltaic Solar Energy Conference**
**CCH Congress Centre**
**Hamburg, Germany**

## October 2011

**17-21** **Solar Power International**
**Dallas Convention Center**
**Dallas, TX**

## November 2011

**9-11** **Solarcon India**
**Hyderabad Convention Centre**
**Hyderabad, India**

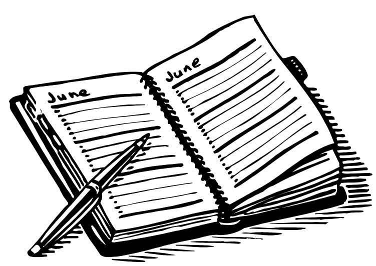

**Table 3: Direct Mask Inspection COO Assumptions**

| Mask Inspection | |
|---|---|
| Throughput | 1 mask per hour |
| Equipment Capacity | Fully loaded at 145 masks per week |
| Tool Loading | 80 masks per week |
| Number of Systems Needed | 1 |
| Equipment Cost | $15,000,000 |
| Systems/Operator | 1 |

**Report 2: Direct Mask Inspection COO (Fully Loaded)**

| | | |
|---|---|---|
| Cost Per System | 15,000,000 | Dollars |
| Number Of Systems Required | 1 | Systems |
| Total Depreciable Costs | 16,220,000 | Dollars |
| Equipment Utilization Capability | 87.10 | Percent |
| Production Utilization Capability | 87.10 | Percent |
| Composite Yield | 100.00 | Percent |
| Good Mask Equivalents Out Per Week | 146.32 | G.M.E.'s |
| Good Mask Equivalent Cost | | |
| With Scrap | 485.58 | Dollars |
| Without Scrap | 485.58 | Dollars |
| Average Monthly Cost | | |
| With Scrap | 308,739 | Dollars |
| Without Scrap | 308,739 | Dollars |
| Process Scrap Allocation | | |
| Equipment Yield | 0.00 | Percent |
| Parametric Limited Yield | 0.00 | Percent |
| Equipment Costs (Over Life of Equipment) | 16,471,193 | Dollars |
| Per Good Mask Equivalent | 308.40 | Dollars |
| Per Good cm2 Out | 1.2850 | Dollars |
| Recurring Costs (Over Life of Equipment) | 9,462,895 | Dollars |
| Per Good Mask Equivalent | 177.18 | Dollars |
| Per Good cm2 Out | 0.7383 | Dollars |
| Total Costs (Over Life of Equipment) | 25,934,088 | Dollars |
| **Per Good Mask Equivalent (Cost Of Ownership)** | **485.58** | **Dollars** |
| Per Good Mask Equivalent Supported | 485.58 | Dollars |
| Per Good cm2 Out | 2.0233 | Dollars |
| Per Productive Minute | 8.09 | Dollars |

Chart 4 shows that the $632 per mask inspected COO value is achieved at a throughput rate of between 0.75 and 0.80 masks per hour. Chart 5 shows the COO value versus utilization and standby time. Standby time was used as the proxy to drive the utilization factor. A mask inspection cost of $632 is approximated at a total utilization rate of 65%. Of course, smaller reductions of throughput and utilization can be combined to achieve the same COO results.

**Image Qualification Impacts on Litho Cluster COO**

The below assumptions are based on inputs from lithography equipment suppliers, users, and publicly available data. These assumptions also allow for a direct comparison to other published data and facilitate the examination of additional scenarios. Table 1 data previously presented was used for both direct mask and image qualification scenarios.

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**Chart 4: Sensitivity Analysis, Direct Mask Inspection Throughput**

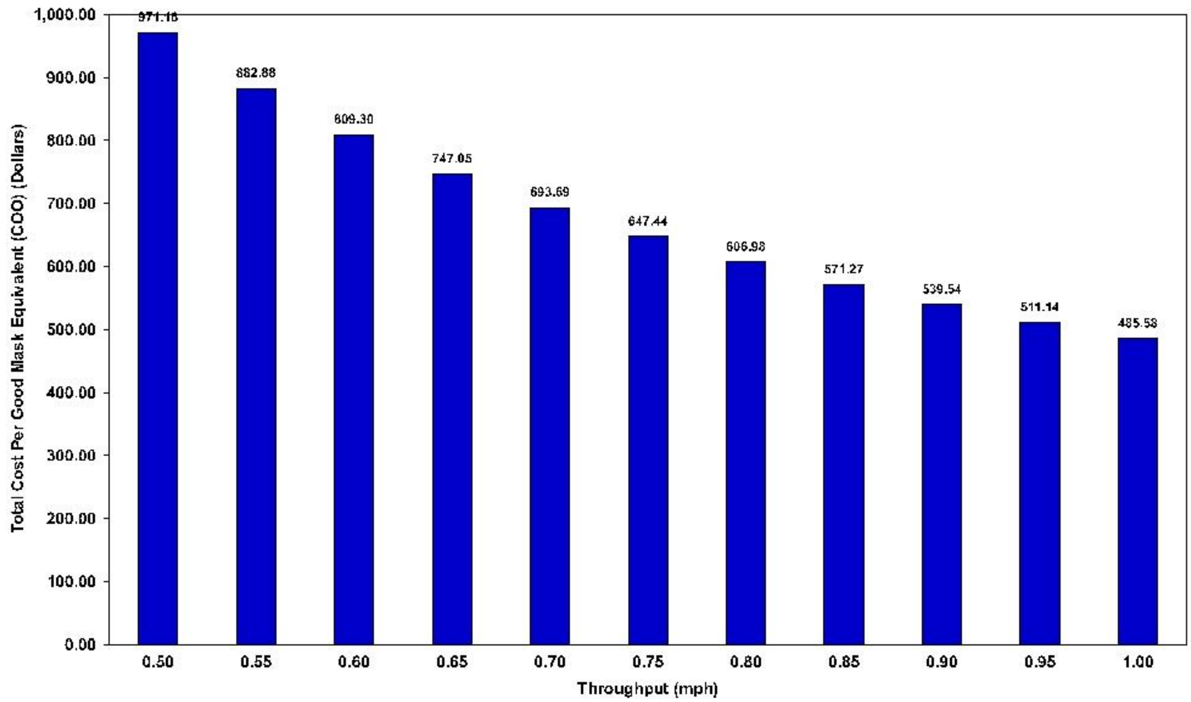


**Chart 5: Sensitivity Analysis, Direct Mask Inspection Availability**

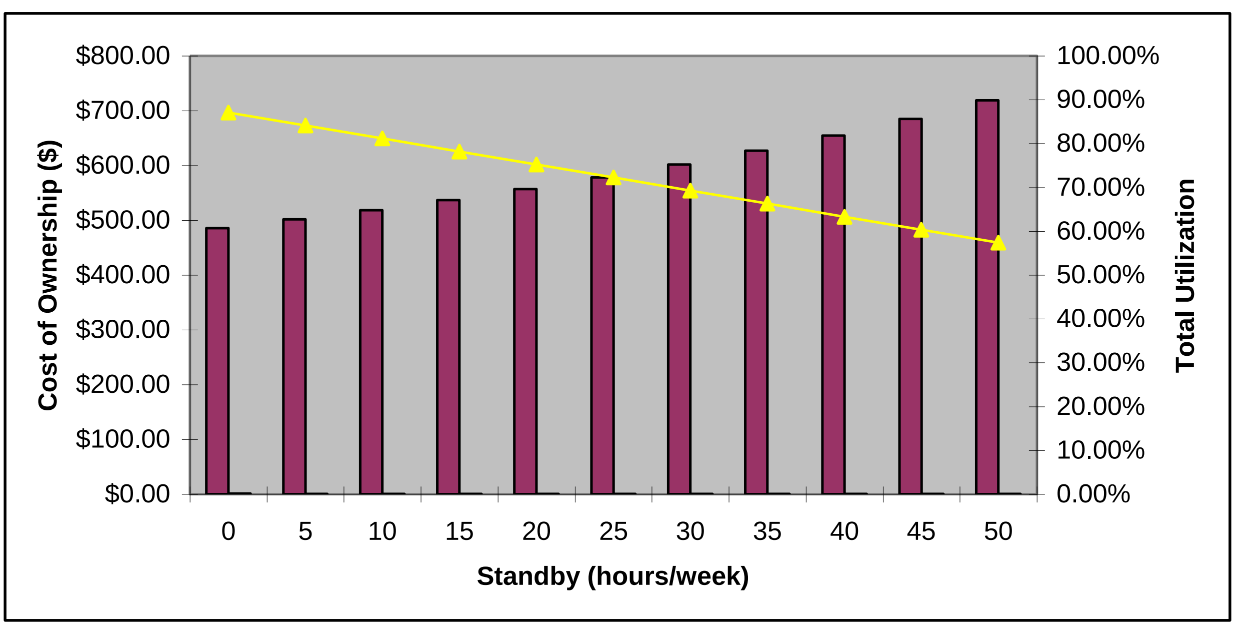

**Table 4: Image Qualification COO Assumptions**

| Direct Mask Inspection | |
|---|---|
| Litho Cell Availability Impact | 6 minutes |
| Yield Loss | none |
| Inspection Cost | $370 |
| Value of Lost Production per Inspection | $500 |
| Mask Inspection Frequency | 500 wafer passes |

**Report 3: Image Qualification COO Results**

| | | |
|---|---|---|
| Cost Per System | 25,000,000 | Dollars |
| Number Of Systems Required | 5 | Systems |
| Total Depreciable Costs | 135,100,000 | Dollars |
| Equipment Utilization Capability | 87.10 | Percent |
| Production Utilization Capability | 85.10 | Percent |
| Composite Yield | 100.00 | Percent |
| Good Mask Equivalents Out Per Week | 80,000.00 | G.M.E.'s |
| Good Mask Equivalent Cost | | |
| With Scrap | 55.33 | Dollars |
| Without Scrap | 55.33 | Dollars |
| Average Monthly Cost | | |
| With Scrap | 19,235,482 | Dollars |
| Without Scrap | 19,235,482 | Dollars |
| Process Scrap Allocation | | |
| Equipment Yield | 0.00 | Percent |
| Parametric Limited Yield | 0.00 | Percent |
| Equipment Costs (Over Life of Equipment) | 136,553,421 | Dollars |
| Per Good Mask Equivalent | 4.68 | Dollars |
| Per Good cm2 Out | 0.0195 | Dollars |
| Recurring Costs (Over Life of Equipment) | 1,479,227,072 | Dollars |
| Per Good Mask Equivalent | 50.66 | Dollars |
| Per Good cm2 Out | 0.2111 | Dollars |
| Total Costs (Over Life of Equipment) | 1,615,780,492 | Dollars |
| **Per Good Mask Equivalent (Cost Of Ownership)** | **55.33** | **Dollars** |
| Per Good Mask Equivalent Supported | 55.33 | Dollars |
| Per Good cm2 Out | 0.2306 | Dollars |
| Per Productive Minute | 103.21 | Dollars |

Table 4 data was used as the base case for image qualification. Some of these parameters are examined later in this report to determine their impact on COO through sensitivity analyses.

The base case COO results for image qualification are listed below in Report 3. While this data is really only useful when compared to the results for direct mask inspection, it does provide a sanity check against the data reported by Bhattacharyya et al. In their paper, which was coauthored by Toshiba Corporation, the authors indicate that a six minute loss of productivity for a litho cluster was valued at $500. The TWO COOL® results shown in Report 3 value a productive minute at $103.21, which agrees to approximately 20%. Given that the authors do not fully disclose their assumptions regarding material costs, this seems to indicate a reasonable level of agreement between the models. The WWK litho cell model includes the costs for photoresist, masks, and developer. The largest area for potential deviation is the assumption for mask life. WWK uses an average value for all designs of 2,000 wafers.

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**Chart 6: Sensitivity Analysis, Production Test Time**

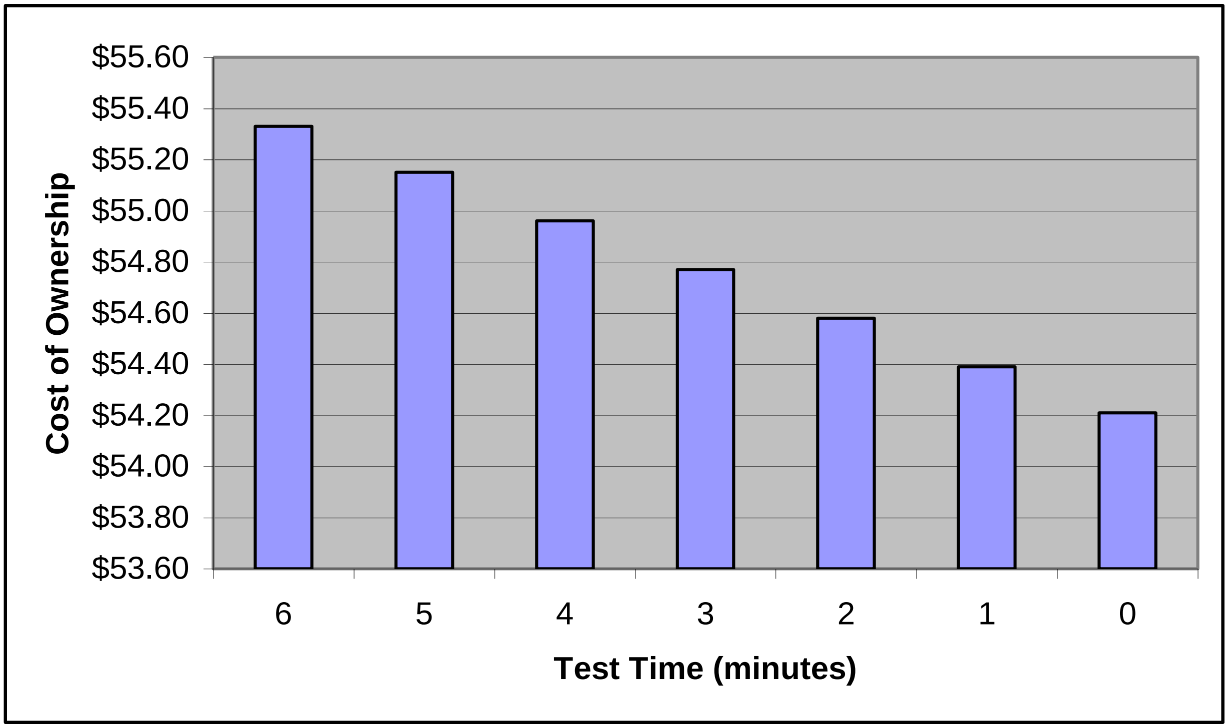
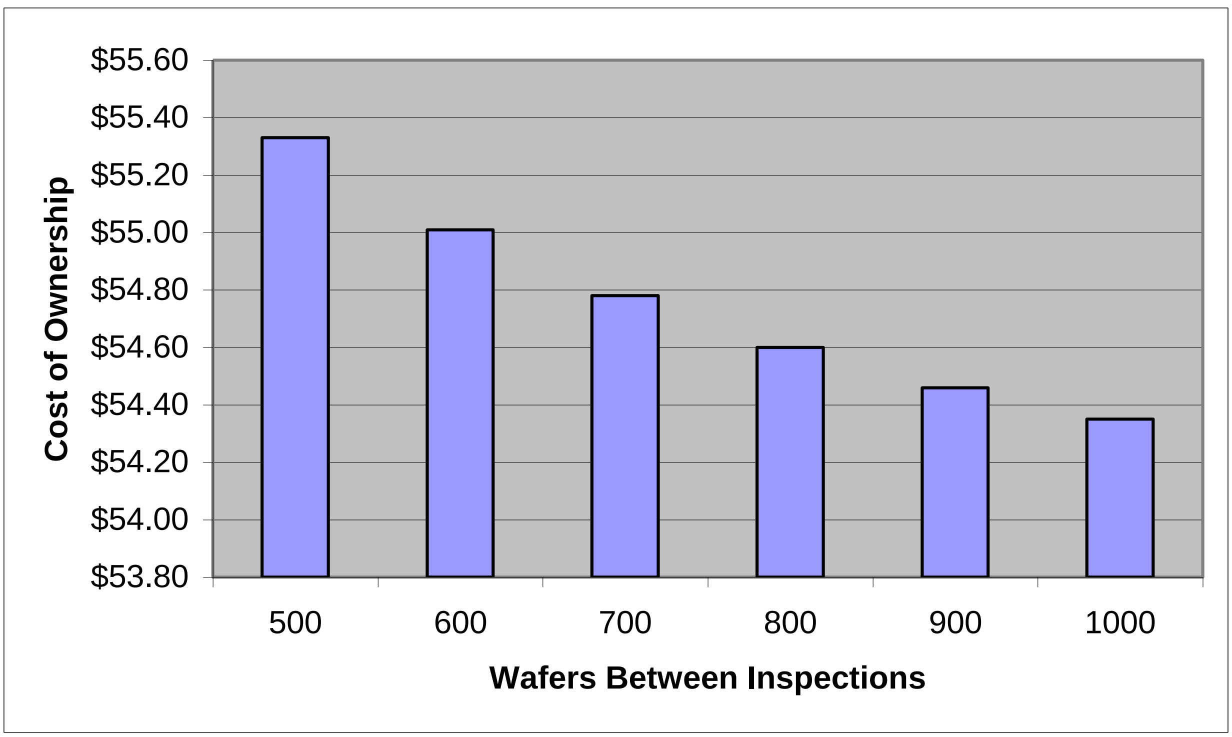



**Chart 7: Sensitivity Analysis, Wafers Between Inspections**



Of course, DRAM and Flash would have longer usage and pure ASIC would have shorter.

One assumption of the image qualification model described above is that it has a six minute impact on litho cluster availability. While it is true that image qualification will impact production qualification time, it is not so clear that the litho cluster will be held for the entire loop of the test wafer through coat, expose, and develop. Chart 6 examines the COO impact for various production test times between zero and six minutes and Chart 7 shows the relationship between COO and the number of wafer passes between image qualifications. It should also be noted that the lost productivity for the image qualification test is only nonzero if the litho cluster is required to make full use of that time and is not just a slight adjustment to the already programmed standby or idle time. Even bottleneck tools are not run at 100% loading due to requirements to maintain cycle time within a reasonable range to meet customer delivery commitments.

**Image Qualification Cost Validation**

The base model for litho cluster COO based on image qualification used a cost per inspection of $370. This data point was taken directly from the paper by Bhattacharyya et al. WWK has attempted to validate this number by building a COO model of the image qualification process. Table 5 indicates the assumptions used in building this model.

**Assumptions**

Report 4 shows the COO results for the assumptions previously listed and Report 5 shows the added SEM review station COO. The calculated cost per test wafer inspection (i.e., wafer inspection plus SEM review) is approximately 40% low. Given that inspection equipment have minimal materials usage, the 40% underestimation must be from overestimating system throughput or system availability. If the models are adjusted for the 160 wafer per week loading and assume dedication to this process alone, the cost rise to $182.38 and $92.43 or about 25% low. The only way to get to the $370 per test wafer inspection cost is to eliminate the SEM review from the model and require two wafer inspection equipment to meet the 160 test wafer inspections per week. This indicates a major difference in assumptions between Bhattacharyya et al and those presented in this report.

**Conclusions**

WWK created an extensive matrix of COO models to examine the equipment sets and inspection flows for direct mask inspection and test wafer image qualification. The models consist of a base 193nm scanner and track that were modified for availability and mask costs impacts. Additionally, models were built to confirm published cost structures for wafer inspection and SEM review as well as direct mask inspection. The fundamental parameters for the litho cluster remained constant regardless of inspection technique.

**Table 5: Image Qualification COO**

| Image Qualification | |
|---|---|
| Throughput | 1.33 masks per hour |
| Equipment Capacity | Fully loaded at 195 wafers per week |
| Tool Loading | 160 |
| Number of Systems Needed | 1 |
| Equipment Cost | $6,000,000 |
| Systems/Operator | 2 |

## Report 4: Image Qualification COO

| | | |
|---|---|---|
| Cost Per System | 2,500,000 | Dollars |
| Number Of Systems Required | 1 | Systems |
| Total Depreciable Costs | 2,720,000 | Dollars |
| Equipment Utilization Capability | 87.10 | Percent |
| Production Utilization Capability | 87.10 | Percent |
| Composite Yield | 100.00 | Percent |
| Good Wafer Equivalents Out Per Week | 292.65 | G.W.E.'s |
| Good Wafer Equivalent Cost | | |
| With Scrap | 58.55 | Dollars |
| Without Scrap | 58.55 | Dollars |
| Average Monthly Cost | | |
| With Scrap | 74,447 | Dollars |
| Without Scrap | 74,447 | Dollars |
| Process Scrap Allocation | | |
| Equipment Yield | 0.00 | Percent |
| Defect Limited Yield | 0.00 | Percent |
| Parametric Limited Yield | 0.00 | Percent |
| Equipment Costs (Over Life of Equipment) | 2,971,193 | Dollars |
| Per Good Wafer Equivalent | 27.82 | Dollars |
| Per Good cm2 Out | 0.0492 | Dollars |
| Recurring Costs (Over Life of Equipment) | 3,282,395 | Dollars |
| Per Good Wafer Equivalent | 30.73 | Dollars |
| Per Good cm2 Out | 0.0543 | Dollars |
| Total Costs (Over Life of Equipment) | 6,253,588 | Dollars |
| **Per Good Wafer Equivalent (Cost Of Ownership)** | **58.55** | **Dollars** |
| Per Good Wafer Equivalent Supported | 58.55 | Dollars |
| Per Good cm2 Out | 0.1035 | Dollars |
| Per Productive Minute | 1.95 | Dollars |
| Per Productive Minute | 3.38 | Dollars |

## Report 5: SEM Review COO

| | | |
|---|---|---|
| Cost Per System | 2,500,000 | Dollars |
| Number Of Systems Required | 1 | Systems |
| Total Depreciable Costs | 2,720,000 | Dollars |
| Equipment Utilization Capability | 87.10 | Percent |
| Production Utilization Capability | 87.10 | Percent |
| Composite Yield | 100.00 | Percent |
| Good Wafer Equivalents Out Per Week | 292.65 | G.W.E.'s |
| Good Wafer Equivalent Cost | | |
| With Scrap | 58.55 | Dollars |
| Without Scrap | 58.55 | Dollars |
| Average Monthly Cost | | |
| With Scrap | 74,447 | Dollars |
| Without Scrap | 74,447 | Dollars |
| Process Scrap Allocation | | |
| Equipment Yield | 0.00 | Percent |
| Defect Limited Yield | 0.00 | Percent |
| Parametric Limited Yield | 0.00 | Percent |
| Equipment Costs (Over Life of Equipment) | 2,971,193 | Dollars |
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| Per Good Wafer Equivalent | 30.73 | Dollars |
| Per Good cm2 Out | 0.0543 | Dollars |
| Total Costs (Over Life of Equipment) | 6,253,588 | Dollars |
| **Per Good Wafer Equivalent (Cost Of Ownership)** | **58.55** | **Dollars** |
| Per Good Wafer Equivalent Supported | 58.55 | Dollars |
| Per Good cm2 Out | 0.1035 | Dollars |
| Per Productive Minute | 1.95 | Dollars |

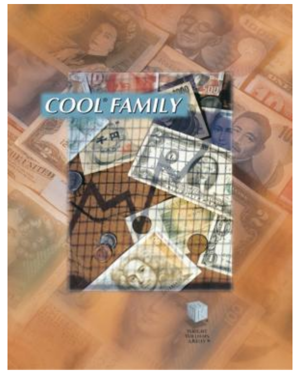
WWK utilized TWO COOL®, the semiconductor industry's COO and overall equipment efficiency (OEE) standard. TWO COOL® is the only software to comply with Semiconductor Equipment and Materials International (SEMI) Standards E10, E35, and E79.

The results of the base models showed that the 193nm litho cluster cost per good wafer equivalent (i.e., COO) was $54.06 including direct mask inspection and $55.33 including image qualification or approximately a 2% difference. This delta is dependent on various operating parameters such as utilization of the litho cluster and throughput of the inspection process. By examining these parameters using sensitivity analysis, it was possible to create plausible scenarios that could eliminate the cost delta. The reduction in litho cell availability losses due to test wafer processing and/or a reduction in the number of image qualifications per week could all lead to a COO value lower than the $54.06 reported for direct mask inspection. In any case, these factors can move the models by a few percent, but given the projected accuracy of the data and variability in fab operating conditions, it is reasonable to state that neither inspection method has an overwhelming cost advantage for the stated set of base assumptions.

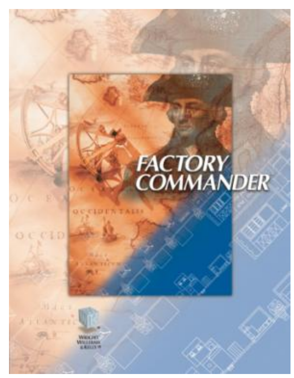
One area that could significantly influence the COO results is any impact on the number of mask sets needed. It has been reported that this is not typically the case but could be a consideration as mask inspection times increase with mask complexity. While the other factors examined in this report were able to move the COO value by up to $1 per wafer pass through the litho cell, the need for any additional masks showed the potential for a cost increase measured in tens of dollars per wafer pass.

**Current WWK Software Versions**

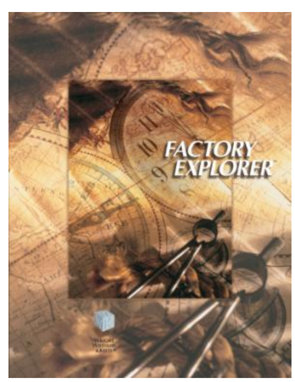
All WWK software has been updated and tested with Windows 7 64bit operating systems. Clients under warranty or covered by a maintenance agreement have received these updates free of charge.




TWO COOL® v3.1.6
PRO COOL® v1.2
PRO COOL® Sort/Test v1.2




Factory Commander® v3.3




Factory Explorer® v2.10.2

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## WWK Hosts Cost of Ownership Seminar at SEMICON West/Intersolar

***WWK and SEMI Cosponsor Event for the 19th Consecutive Year***

Wright Williams & Kelly, Inc. (WWK), the world's preeminent cost of ownership software and consulting services company, announced today that it will be presenting its highly acclaimed seminar, "Understanding & Using Cost of Ownership," during SEMICON West/Intersolar North America. "Understanding & Using Cost of Ownership" will be held at the San Francisco Marriott on Thursday, July 14 from 9am to 5pm. This seminar covers all aspects of Cost of Ownership (COO) and Overall Equipment Efficiency (OEE) from fundamentals to hands-on applications and has been enhanced to meet the needs of the photovoltaics (PV) industry.

There is limited seating available for this seminar, so please contact Semiconductor Equipment and Materials International (SEMI) today to guarantee your place in this once-a-year event (http://semiconwest.org/node/6551). As an added benefit, WWK's software maintenance clients qualify for a 20% discount off the list price of the seminar if booked directly with WWK.

With more than 3,000 users worldwide, Wright Williams & Kelly, Inc. is the largest privately held operational cost management software and consulting company serving technology-dependent and technology-driven organizations. WWK maintains long-term relationships with prominent industry resources including SEMATECH, SELETE, Semiconductor Equipment and Materials International (SEMI), national labs, and universities. Its client base includes nearly all of the top 20 semiconductor manufacturers and equipment and materials suppliers as well as leaders in nanotechnology, micro-electro-mechanical systems (MEMS), thin film recording heads, magnetic media, flat panel displays (FPD), solid state lighting/light emitting diodes (SSL/LED), and photovoltaics (PV).

WWK's product line includes TWO COOL® for detailed process step level cost of ownership (COO) and overall equipment efficiency (OEE), PRO COOL® for process flow and test cell costing, Factory Commander® for full factory capacity analysis and activity based costing, and Factory Explorer® for cycle time reduction and work in progress (WIP) planning. Additionally, WWK offers a highly flexible product management software package that helps sales forces eliminate errors in product configuration and quotation processes.

SEMICON® West2011
July 12–14, 2011
Moscone Center, San Francisco, California

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# Another PV Manufacturer Teams with WWK

***Partnership Focused on Improvements in PV Production Economics***

Wright Williams & Kelly, Inc. (WWK), the global leader in cost and productivity management software and consulting services, announced today a partnership with an innovative photovoltaic (PV) cell manufacturer. The partnership provides operational modeling software tools to validate and demonstrate the cost advantages of their unique intellectual property (IP).

"Scaling to commercial volumes is challenging on both a cost per watt and total cost basis," stated David Jimenez, WWK's President. "WWK's operational modeling solutions, such as TWO COOL® and Factory Commander®, provide the basis for making optimal decisions in cost reduction roadmaps by not only addressing costs but the tradeoffs between cost and efficiency. In the end, it is about the cost per watt and we are excited to be working on these new manufacturing approaches."

With more than 3,000 users worldwide, Wright Williams & Kelly, Inc. is the largest privately held operational cost management software and consulting company serving technology-dependent and technology-driven organizations. WWK maintains long-term relationships with prominent industry resources including SEMATECH, SELETE, Semiconductor Equipment and Materials International (SEMI), national labs, and universities. Its client base includes nearly all of the top 20 semiconductor manufacturers and equipment and materials suppliers as well as leaders in nanotechnology, micro-electro-mechanical systems (MEMS), thin film recording heads, magnetic media, flat panel displays (FPD), solid state lighting/light emitting diodes (SSL/LED), and photovoltaics (PV).

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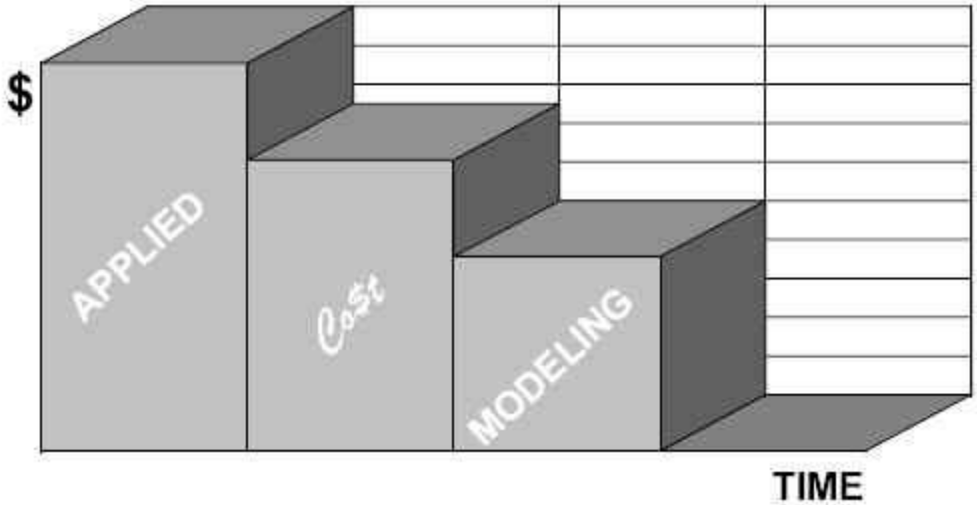
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