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APPLIED Co$t MODELING

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Determining ROI and Productivity Benefits of Lithographic Simulation

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Abstract
This paper will examine the financial benefits of lithographic simulation (LS) as applied to semiconductor manufacturing. The financial analysis is based on three assumptions regarding the benefits of employing an LS strategy, accelerated process development, improvements in time to volume manufacturing, and yield improvements. The financial impact of these assumptions were modeled using Wright Williams & Kelly, Inc.'s Factory Commander® cost and resource evaluation software platform utilizing a sample 130-nm, 6-level-copper, 25-masking-level process flow.

LS Benefit Assumptions
There are three basic assumptions made about how LS can impact a semiconductor fab. These assumptions are:

- Accelerate process development
  - Enable semiconductor manufacturers to maximize the use of their current-generation exposure tools
  - Improve time to market by early definition and verification of lithography strategies

[Continued on Page 3]

Editorial Board

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Calendar of Events

June

6-7 **International Strategic Symposium**
Osaka, Japan

8-10 **Flat Panel Display Taiwan**
Taipei, Taiwan

July

12-14 **SEMICON West**
San Francisco, CA

14 **Understanding and Using Cost of Ownership Workshop**
San Francisco, CA

September

12-14 **SEMICON Taiwan**
Taipei, Taiwan

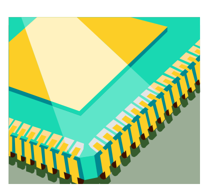
13-15 **International Symposium on Semiconductor Manufacturing (ISSM)**
San Jose, CA

October

19-21 **FPD International**
Yokohama, Japan

24-26 **ISMI Symposium on Manufacturing Effectiveness**
Austin, TX

Remember to drop by our booth at SEMICON West. WWK will be located in Moscone Hall North, booth #5557



[Continued from Page 1]

- Improve time to volume manufacturing
  - o Enable reliable and consistent prediction of the output of the lithography process
  - o Enable methodical tuning of the lithography process, design structures, and mask layout
- Maximize productivity and yield
  - o Allow the development of processes and products with significantly increased production yields by reducing the occurrence of faults
  - o Increase the yield advantage further by closing the current gap between chip design and manufacturing using Design for Manufacturability (DFM) software tools.

Analysis Approach

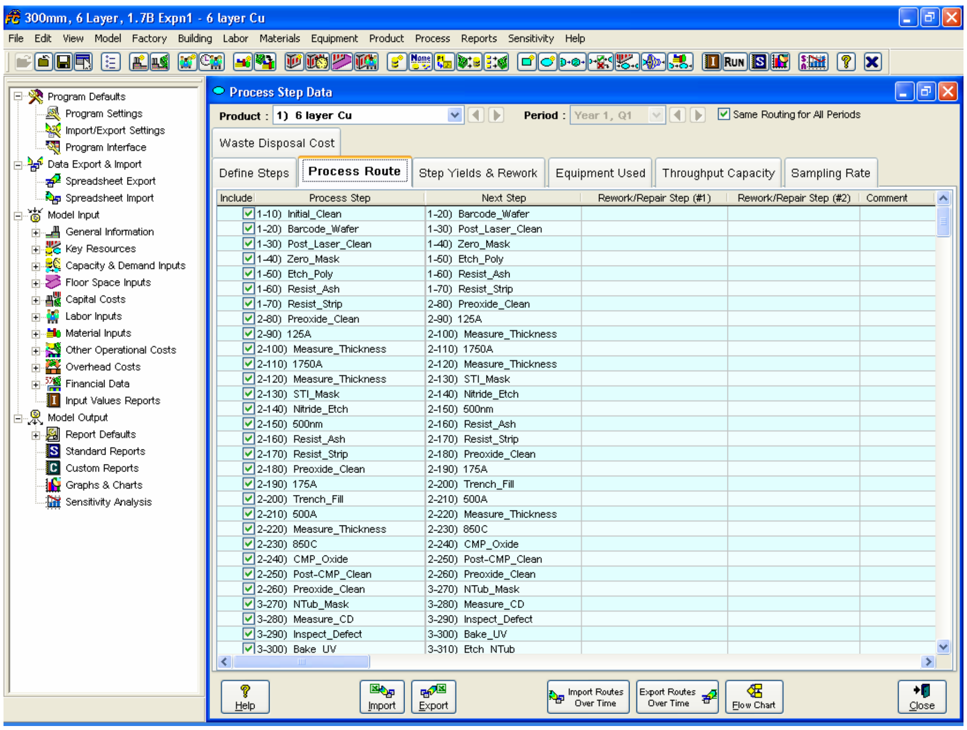
The financial analyses of the above listed assumptions were done by evaluating the impact they have on an example fab dataset based on:

- 130-nm/Cu process
- 20,000 300-mm monthly wafer starts (ramped)
- 25 masking levels

The modeling work was done using WWK's Factory Commander® software. Developed with Sandia National Laboratories, Factory Commander® is a Cost and Resource Evaluation software platform that can be applied to any discrete manufacturing or assembly operation. It performs high-level cost analyses of overall factory and individual product costs, manufacturing capacity, and revenues.

Since it is not possible to determine the actual impact of the assumptions for all fab conditions, sensitivity analyses were run to provide a range of results based on a potential range of input data. Once the model was developed and run, critical outputs were examined:

- Return on Investment (ROI)
- Net Present Value (NPV)
- Time to Breakeven
- Payback Period



Factory Commander® User Interface Showing Example Process Flow

Baseline Model Financials

As a starting point, the example 130-nm copper process model was run in its baseline condition. This means that none of the LS assumptions were included in this run. The results are shown below.

Model Name : **300mm, 6 Layer, 1.7B Expn1 ramp**

Interest Rate (%)	Break Even Time Frame, No Interest (weeks)	Break Even Time Frame, w/ Interest (weeks)	Payback Period, No Interest (weeks)	Payback Period, w/ Interest (weeks)	Net Present Value, No Interest (M$)	Net Present Value, with Interest (M$)	Internal Rate of Return (%)	Return on Investment (%)
10	158	161	296	302	1917	1003	35	21

The Interest Rate in all models was set to 10%. This value is used to determine the discounted cash flow and is represented by those columns labeled "w/Interest." The Break Even Time Frame is the number of weeks before the cash inflows and outflows equalize. This is a point in time and not cumulative. The Payback Period is the cumulative time when all prior inflows and outflows balance. NPV is the current value of all investments and future cash flows based on the Interest Rate previously described. A non-discounted value is also presented. Two additional items are reported, Internal Rate of Return and ROI. The baseline model assumes no yield losses and returns a $1.003B NPV over its six-year life.

Modeling Accelerated Development

LS claims to be able to shorten the time to develop new semiconductor products. This shortened development cycle has a number of potential impacts on the profitability of the wafer fab. These possible impacts are:

- Year 1 pricing premium
- Early entrance to market captures higher share/design wins
- Market share drives higher production volume and faster ramp
- Design wins exclude competition from eroding market share and pricing premium

To simplify the analysis, we used the single variable impact of a year 1 pricing premium. The base model was run under two new pricing scenarios (base model was $4,500/wafer revenue), 10% ($4,950) and 20% ($5,400) premiums. It should be noted that the wafer starts in year 1 are ramped and, therefore, any pricing premium will be reduced due to a smaller number of wafer starts. There were no assumptions regarding a lengthening of the market window and the model was still run for a six-year horizon.

The results of the analyses show a considerable impact. Each 10% improvement in year 1 pricing provides:

- 1% increase in ROI
- $60M increase in six-year NPV (10% discount factor)

Model Name : **300mm, 6 Layer, 1.7B Expn1 ramp, 10% Year 1 Premium**

Interest Rate (%)	Break Even Time Frame, No Interest (weeks)	Break Even Time Frame, w/ Interest (weeks)	Payback Period, No Interest (weeks)	Payback Period, w/ Interest (weeks)	Net Present Value, No Interest (M$)	Net Present Value, with Interest (M$)	Internal Rate of Return (%)	Return on Investment (%)
10	152	156	286	291	1985	1065	38	22

Model Name : **300mm, 6 Layer, 1.7B Expn1 ramp, 20% Year 1 Premium**

Interest Rate (%)	Break Even Time Frame, No Interest (weeks)	Break Even Time Frame, w/ Interest (weeks)	Payback Period, No Interest (weeks)	Payback Period, w/ Interest (weeks)	Net Present Value, No Interest (M$)	Net Present Value, with Interest (M$)	Internal Rate of Return (%)	Return on Investment (%)
10	147	150	275	281	2052	1126	40	23

- 2.5 month shorter payback period
- 1.5 month shorter route to breakeven operations

Modeling Time to Volume

An additional claim for LS is the ability to assist in ramping up production at a faster rate than would otherwise be achievable. Since the model already was based on a ramp from 5,000 wafer starts per month to 20,000 over a one-year period, the analyses accelerated the ramp rate from 12 months to 9 months to 6 months.

The results show a lesser, but still significant, benefit for the one quarter acceleration. This is due to the fact that the last quarter of year 1 is almost at full production. By moving full production in an additional quarter, the impact is similar to a 20% year 1 price premium.

Each quarter of ramp acceleration gains:

- 1% in ROI
- $35-70M in 6-year NPV (10% discount factor)
- 1-2 month shorter payback period

Modeling Yield

The last LS assumption to be modeled was the ability to improve yields by optimizing mask designs around lithographic performance. The design engineer working in conjunction with the lithography engineer can simulate the on-wafer performance of mask images and make corrections or changes to features before taping out a new design. This not only will provide better first-pass yields but also reduce re-spin costs and development time lines. These last items are not considered in this sensitivity analysis.

The base model assumes 100% yield at each step in the process. In order to measure the impact of this LS assumption, we ran a number of models with varying yield at each lithographic step (see below):

- Zero_Mask
- STI_Mask
- NTub_Mask
- NVt_Mask
- PVt_Mask
- Gate_Mask
- P_LDD_Mask
- N_LDD_Mask
- P_S/D_Mask
- N_S/D_Mask
- Implant_7_Mask
- Contact_Mask
- Metal_1_Mask
- Metal_2_Mask
- Via_2_Mask

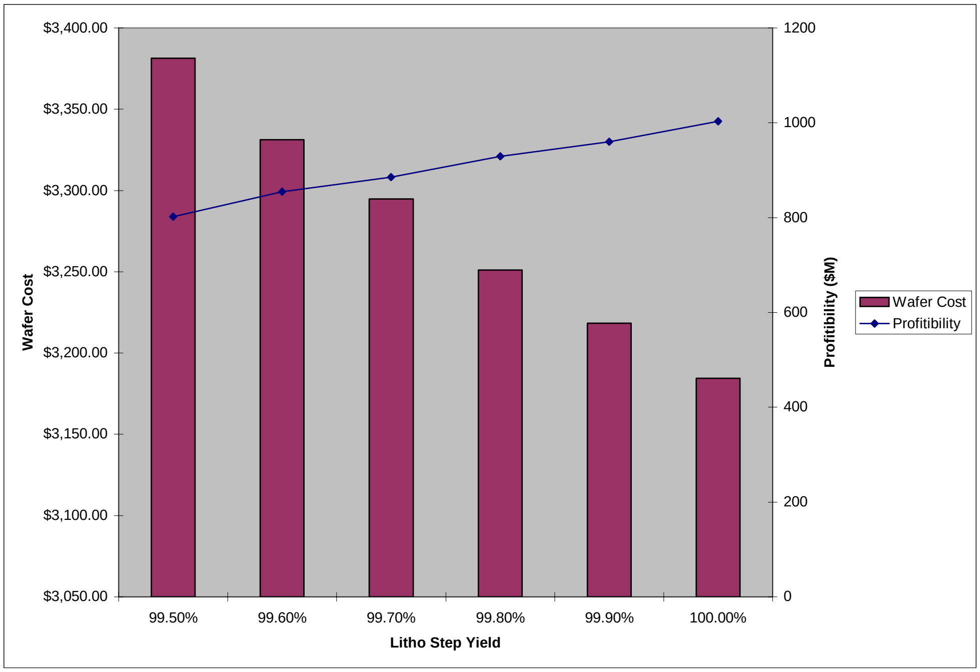
Model Name : **300mm, 6 Layer, 1.7B Expn1 ramp, 1 Quarter Acceleration**

Interest Rate (%)	Break Even Time Frame, No Interest (weeks)	Break Even Time Frame, w/ Interest (weeks)	Payback Period, No Interest (weeks)	Payback Period, w/ Interest (weeks)	Net Present Value, No Interest (M$)	Net Present Value, with Interest (M$)	Internal Rate of Return (%)	Return on Investment (%)
10	155	158	292	298	1958	1040	37	22

Model Name : **300mm, 6 Layer, 1.7B Expn1 ramp, 2 Quarter Acceleration**

Interest Rate (%)	Break Even Time Frame, No Interest (weeks)	Break Even Time Frame, w/ Interest (weeks)	Payback Period, No Interest (weeks)	Payback Period, w/ Interest (weeks)	Net Present Value, No Interest (M$)	Net Present Value, with Interest (M$)	Internal Rate of Return (%)	Return on Investment (%)
10	148	151	284	289	2038	1113	40	23

- Metal_3_Mask
- Via_3_Mask
- Metal_4_Mask
- Via_4_Mask
- Metal_5_Mask
- Via_5_Mask
- Metal_6_Mask
- Via_6_Mask
- BondPad_Mask
- Passivation_Mask



The yield at each step was ramped from 99.5% to 100%. All steps were treated equally.

The results represented in the below graph indicate that for each 0.10% improvement in lithographic step yield:

- Net Present Value increases by $40M
- Wafer cost decreases by $50/wafer
- Approximately $12M/year in reduced costs
- Payback period decreases by 1 month
- Return on Investment increased by ~1%

Conclusions

It has been shown that Factory Commander® can easily evaluate the potential impacts of LS as described by the benefit assumptions. The potential value of LS has been demonstrated to be of such high return as to make the implementation pay back almost instantaneous.

Accelerated development results indicated a $60M Net Present Value improvement based on a 10% year 1 price premium. A 1-to-2 quarter faster production ramp rate showed a $35-70M Net Present Value improvement. Yield improvement results were $40M for each 0.10% increase in lithographic step yield.

Using the lower of these numbers yields:

- An LS investment ROI of over 1000X
  - Assuming a $100K investment in LS
- A pay back period of 1.6 days

Even if the benefit assumptions discussed in this paper were off by 200X, the pay back would still be less than 1 year.

WWK Offers Free Automotive Cost of Ownership Software

Determine the COO of Motor Vehicles Before You Buy

May 5, 2005 (Pleasanton, CA) –Wright Williams & Kelly (WWK), a cost & productivity management software and consulting services company, announced today the availability of a free cost of ownership calculator for the motor vehicle buying public. The calculator is available on its web site (www.wwk.com) under the "Products" link and is based on the company's powerful TWO COOL® Cost of Ownership (COO) and Overall Equipment Efficiency (OEE) software.

"WWK was founded on the principal of helping our clients better manage their billion dollar asset portfolios," stated David Jimenez, President of Wright Williams & Kelly, Inc. "Purchase analysis tools are rarely made available to the personal consumer. We felt that this application was a great way to introduce our strengths to a broader audience while providing a real benefit in these times of escalating fuel and motor vehicle purchase prices."

With more than 2,800 users worldwide, Wright Williams & Kelly, Inc. is the largest privately held operational cost management 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 nano-technology, MEMS, thin film record heads, magnetic media, flat panel displays, and solar panels.

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 WIP planning. Additionally, WWK offers a highly flexible product management software package that helps sales forces eliminate errors in product configuration and quotation processes.

Factory Explorer® v2.9 Update

The development of the next release of Factory Explorer® is well underway. The major features that have been added to the enhancement list include a series of operator modeling capabilities based on WWK-funded research at the University of Arkansas. These added capabilities allow for varying operator headcount by shift, skill set descriptions allowing for cross-equipment training and productivity deltas, overtime scheduling and payroll, and varying shift lengths. Additional capability is being added to allow for a master process flow to call sub-flows.

This upgrade will be available at no charge to all Factory Explorer® maintenance agreement clients.

Cost of Ownership and Return on Investment Analysis of the Fabworx™ Robotic Arm

Determining the impact of Cost of Ownership (COO) and Return on Investment (ROI) is crucial in the high-tech decision-making process. To analyze the financial impact of upgrading an Applied Materials' Centura® System with a Fabworx Solutions HP Robotic Arm, a cost-of-ownership model was developed and is described in this article. Using TWO COOL®, the industry-standard software from Wright Williams & Kelly, Inc., a comprehensive return on investment model was generated for several tool performance areas using actual data provided by customers.

Overview

A number of AMAT Centura systems were upgraded with the Fabworx Robot. These upgrades were performed to improve a variety of issues, including reliability, throughput and yield. The financial impacts of these upgrades were analyzed by Fabworx Solutions. WWK's TWO COOL cost-of-ownership analysis software was used to evaluate the ROI and payback interval of these Fabworx robot upgrades. Incorporating full SEMI Standards compliance for analyzing COO and OEE, TWO COOL is accepted as the industry standard and is widely used by major semiconductor manufacturers and equipment suppliers. Using this software application, a model was generated that incorporates customer-supplied data taken before and after the upgrades were performed. This customer data was collected from several upgrades throughout multiple fabs over a period of twelve months.

This article provides details on the model used, the results obtained, the Fabworx Robot and the TWO COOL software application. Additional information can be provided by contacting either Fabworx Solutions (www.fabworx.com) or Wright Williams & Kelly (www.wwk.com).

Results

The results of this analysis indicate that the Fabworx Robot upgrade provides substantial return on investment. This return is obtained within several performance improvement areas that were independently measured and analyzed:

- Reliability is improved, providing a cost savings on replacement parts, labor and tool downtime.
- Wafer placement repeatability is improved, reducing backside pressure faults and thus increasing tool availability.
- Tool throughput is increased, effectively providing incremental capacity.
- Wafer scratching due to robotic inaccuracies is eliminated, resulting in an immediate yield increase.
- Wafer-handling-induced particles, another source of yield loss, are greatly reduced.

The Hardware

The Applied Materials' Endura and Centura Systems are among the most successful manufacturing platforms in use today. At the core of these cluster tools are the HP and VHP wafer-handling robots.

Initially designed in the 1980's, these robots were considered state-of-the art. Over time, however, robot limitations have resulted in reduced system productivity and yield:

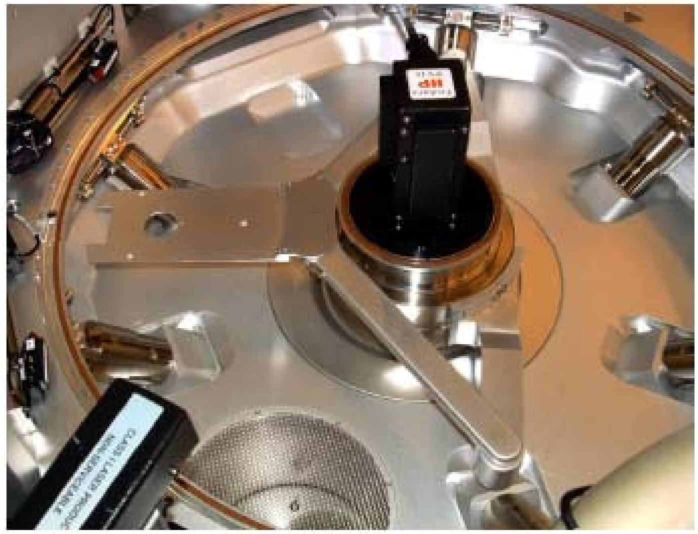
- Bearings located at the hub, elbow and wrist frequently wear out and require replacement, resulting in excessive costs for parts, labor and tool downtime.
- Wafers slide while on the blade, leading to placement inaccuracy.
- In several cases, the throughput of these systems is limited by the robot's wafer-handling speed.
- Wafer scratching is commonly exhibited, due to robot droop. As a result, the robot blade contacts the topside of a wafer while extending into the cassette.
- Robot-induced particles are generated from wafers sliding on the blade (creating aluminum and nickel particles), and exposed stainless steel bearings in the hub, elbow and wrist assemblies repeatedly colliding (creating ferrous particles and gaseous molecular contamination from bearing grease).

The Fabworx Solutions Upgrade

Fabworx Solutions has developed a next-generation Robotic Arm upgrade for these systems that incorporates advanced materials in its design to improve precision and structural integrity. The design also increases system reliability, wafer placement repeatability and tool throughput.

Installed in high-volume production fabs since early 2003, the Fabworx Robot's design addresses performance problems exhibited in the OEM robot:

Figure 1
Fabworx Solutions' Robotic Arm



- The Robot is designed to a specification of 11 million Mean Cycles Between Failure (MCBF), a ten-fold improvement over the previous generation of OEM robots. Design enhancements also increase bearing life, reducing preventive maintenance requirements, downtime and parts cost.
- Wafers rest on three perflouroelastomer pads with a high coefficient of friction, eliminating wafer sliding and increasing placement accuracy.
- Since the Fabworx Robot can safely move wafers significantly faster than the original robot, wafer-handling speed is increased and a higher throughout can be achieved.
- Wafer scratching is eliminated with the Fabworx Robot. Its blade provides more wafer-to-wafer clearance within the cassette, offers more precise adjustability throughout and will not droop.
- Sealed, ceramic bearings are used, with minimal amounts of high-quality lubricant. Robot-induced particles on both the frontside and backside of wafers are substantially reduced.

The Software

Originally developed for SEMATECH, Wright Williams & Kelly's TWO COOL software is widely accepted as the industry standard for analyzing COO and OEE. This feature-rich application incorporates full SEMI Standards compliance, and is equally valuable in evaluating the financial impact of both capital purchases and system upgrades. Along with a state-of-the-art graphical user interface, TWO COOL offers automated report and chart generation, sensitivity analysis, a built-in database and multiple analysis modes.

During this analysis, the software proved highly effective for modeling the financial ramifications of this type of upgrade. COO as well as OEE is accurately modeled, and before-and-after comparisons were quickly calculated and evaluated.

The Model

To generate the cost-of-ownership analysis, several parameters were entered into the TWO COOL software application to define the hardware and process used. In addition, actual customer-supplied, before-and-after performance data was used.

Hardware Configuration

The following system configuration was used:

- A single-robot, three-chamber Centura 5200 system with an ElectroStatic Chuck (ESC).
- An identical process for each of the three chambers.
- Industry-typical system parameters.

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Data
All data used in this analysis was customer-supplied. Measurements were taken before and after the Fabworx upgrades were performed. The data encompasses several upgrades, performed at several customer sites, over a period of twelve months.

To remain conservative in the modeling calculations, a lesser improvement than what was actually achieved was used to determine ROI.

Cost and Performance Parameters
Table 1 summarizes the cost and productivity parameters used in this analysis. These parameters are based on system specifications, typical industry performance and actual customer installation data.

Modeling Calculations
A baseline COO analysis was first run, providing an initial cost-per-wafer result. Once this was accomplished, customer-supplied data was entered for each performance improvement area.

After data was entered, the new cost-per-wafer value was subtracted from the initial cost-per-wafer value, netting the cost savings per wafer provided by the Fabworx upgrade. Multiplying this per-wafer savings by the number of wafers-per-year run through the system yielded a one-year ROI. An annual payback interval (the amount of time required to achieve ROI) was then calculated.

NOTE: Typically an ROI calculation takes into account the entire useful life of the product. While a substantially larger return on investment is calculated when the lifetime of the Fabworx Robot is considered, only the first-year ROI results are presented, to emphasize the immediate savings and short-term benefits achieved by this upgrade.

Table 1
Assumptions for COO Model

Assumption	Value
Overall Equipment Effectiveness (OEE)	69%
Wafer Size	200 mm
Tool Availability	87%
MTBF	200 Hrs.
MTTR	10 Hrs.
Original Equipment Cost	$2,000,000
Throughput	40 Wafers/Hr.
Completed Wafer Manufacturing Cost	$900
Materials Cost	$1.00/Wafer
Warranty	None
Baseline Cost of Ownership	$4.01/Wafer
Price of Fabworx Upgrade Kit	$42,400

<u>The Detailed Analysis Results</u>
The following pages detail this analysis, in five separate performance areas:

- Maintenance-Related Costs
- Throughput
- Wafer Placement Repeatability
- Robot-Related Wafer Scratches
- Robot-Related Particles

As demonstrated in this analysis, the ROI for the Fabworx Robot is far more significantly impacted by its ability to improve the system's productivity and yield, than by improving its reliability.

<u>Financial Implications of Maintenance-Related Tool Improvements</u>

Problem
Several maintenance issues are present in the OEM robot:

- Hub, elbow and wrist bearings wear out, requiring replacement parts, repair labor and tool downtime.
- Blades and wrist mounts bend from process heat and occasional contact with chamber walls, slit valves, etc. Replacement is sometimes required.
- Robot alignment is difficult and imprecise, leading to additional maintenance.

Solution

- Fabworx bearings are ceramic, providing long life. Hub bearings employ Vespel separators to further reduce wear. Stronger bearing spacers keep bearings in place, reducing collisions that cause wear.
- Blade and wrist mounts are stronger, reducing wear and droop.
- All robot components are stiff and more precise. Overall Z adjustment allows first-order alignment, while the blade adjustment mechanism provides for very precise final alignment.

Customer Data

All customers report that OEM robot maintenance is required at least once per year, while most report that this is required every six months. A maintenance event assumes rebuilding the arm, replacing the bearings, and the related tool downtime required for realigning and re-teaching the tool.

This calculation assumes one maintenance interval per year. However, when the norm is applied (maintenance every six months), payback is substantially faster.

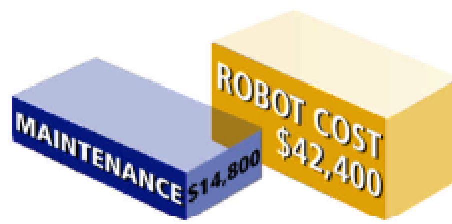
CALCULATION

Bearing cost	$4,000 per set
Labor	$800 (80/Hour X 10 Hours)
Tool Downtime	$10,000 (1,000/Hour X 10 Hours)
Yearly Cost	$14,800

RETURN ON INVESTMENT

ONE-YEAR ROI	34.9% ($14,800)
PAYBACK INTERVAL	2.86 years

ONE-YEAR ROI



<u>Financial Implications of Throughput Improvements</u>

Problem

The throughput of Endura and Centura systems is often limited by the OEM robot's wafer-handling speed:

- When process steps are short, wafer-handling time is significant relative to processing time.
- Customers sometimes elect to install three chambers on a system instead of four, since adding an additional chamber would not substantially increase throughput, due to robot limitations.
- Complex wafer move sequences often create high wafer-handling overhead.

The OEM robot's extend and retract time is 1.75 seconds. Wafer sliding prevents any improvement in this parameter. In addition, running at higher speeds would prematurely wear out robot components, due to lack of structural integrity.

Solution

At full speed, extend and retract time for the Fabworx Robot is 0.75 seconds; rotational moves are similarly improved. Since its design is more structurally robust and the perflouroelastomer pads prevent the wafer from sliding, the Robot can be operated at maximum speed.

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Customer Data
Using the Fabworx Robot, a large DRAM customer with several short process steps conducted tests to measure throughput improvements. A common recipe was run on the three-chamber Centura tool. Three different process times were used for this test, and the results were compared to data collected on the OEM robot. Table 2 provides these results. Other customers have reported throughput increases of between 5% and 34%, with an average increase of 15%.

Table 2
Comparison of Throughput on Fabworx Robot vs. OEM Robot

40-Second Recipe	27.1% Increase
60-Second Recipe	24.7% Increase
90-Second Recipe	11.5% Increase

Calculation
Based on customer data, this calculation assumes an average throughput increase of 15%.

At 40 wafers per hour, the cost per wafer is $4.01. When throughput is increased by 15% (46 wafers per hour), the resulting cost per wafer is decreased to $3.65. This yields a cost-per-wafer savings of $0.36.

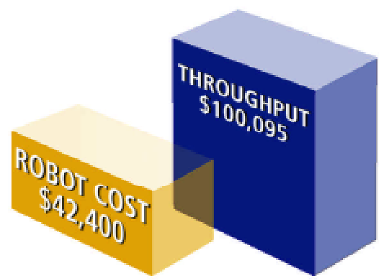
At 46 wafers per hour, the Fabworx Robot will process 278,042 wafers/yr. ([40 wafers/hr. X 24 hrs./day X 365 days/yr.] X 69% OEE).

RETURN ON INVESTMENT

ONE-YEAR ROI	236% ($100,095)
PAYBACK INTERVAL	22 weeks

When a group of tools is collectively upgraded, the capacity of that group can be increased by the equivalent of one entire system, without the associated capital cost, footprint and overhead.

ONE-YEAR ROI



Financial Implications of Wafer-Placement Repeatability Improvements

Problem
Several sources of wafer placement errors are exhibited by the OEM robot:

- Wafers slide on the blade, resulting in poor placement accuracy.
- Robot joints loosen over time and the hub assembly lacks structural integrity, causing backlash. Backlash is the space, or play, between gears and other mechanical elements within the robot. This is a prime contributor to wafer misplacement, and becomes more prevalent over time.

In tools configured with ElectroStatic Chucks (ESC), wafer placement errors often result in backside pressure faults. Customers reported placement inaccuracy as one of the two causes of these faults (Figure 2). When these occur, the chamber typically must be opened: this results in a wet clean, translating to between 8 and 10 hours of downtime.
In other cases, wafer placement errors affect process uniformity, due to nonrepeatable placement of the wafer within the process zone.

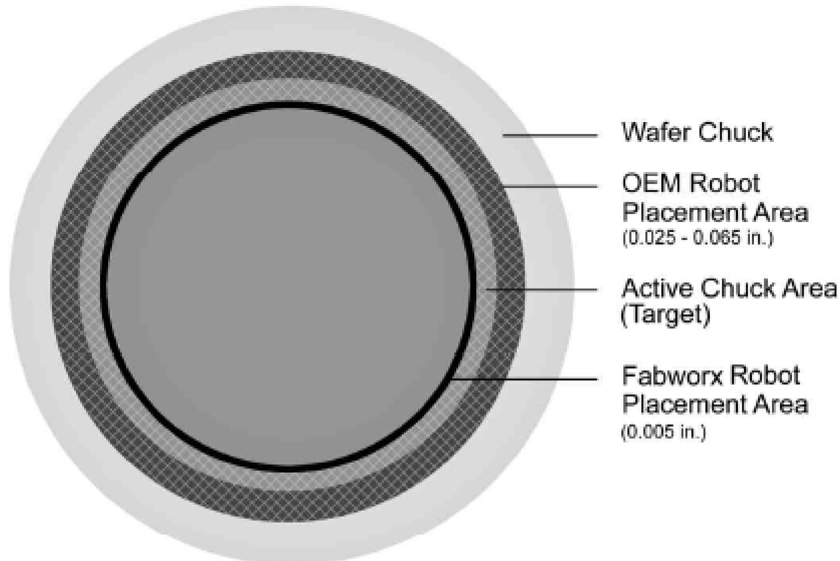
Solution
- The Fabworx Robot uses perflouroelastomer pads to prevent the wafer from sliding.
- All bearings are heat-pressed, creating extremely tight joints.
- The hub assembly is structurally robust and stiff, eliminating extraneous movement.

These design enhancements substantially reduce backlash and provide far better placement accuracy. Since wafer placement is more repeatable, backside pressure faults are reduced along with associated chamber downtime.

Customer Data
Customer data demonstrates that backside pressure faults were reduced by 90% after upgrading to the Fabworx Robot. Table 3 illustrates the repeatability of both a new and older OEM robot and compares them to the Fabworx Robot.

Calculation
Only equipment downtime is used to financially model wafer-placement repeatability. Associated parts usage or other costs of wet cleans are not considered in this calculation. Financial implications of process nonuniformity have not been modeled as data has not yet been collected on this issue. Since process nonuniformity affects product yield, any improvement will have large financial benefits.

Figure 2
Wafer Placement

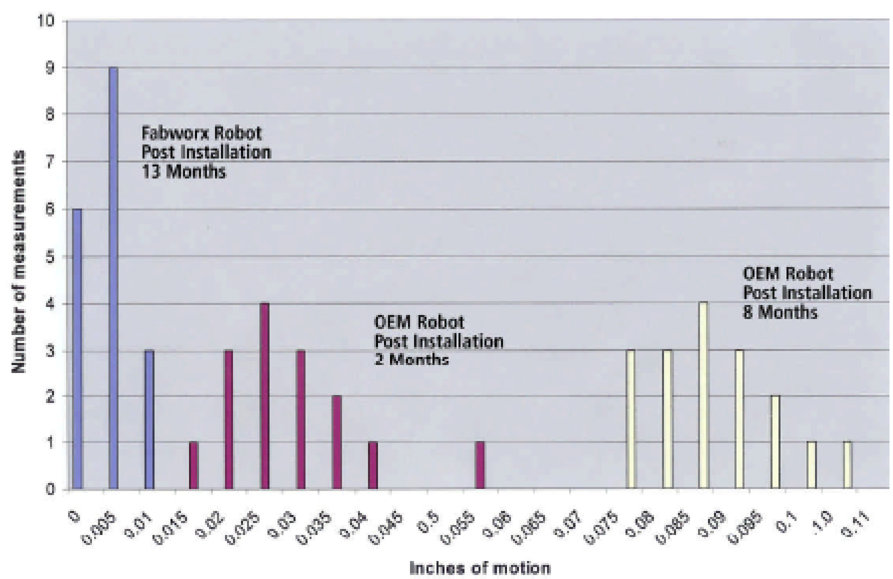


Fabs with tools utilizing ElectroStatic Chucks (ESC) generally report one weekly chamber-down event per tool. For this calculation, a reduction of 75% in backside pressure faults is assumed.

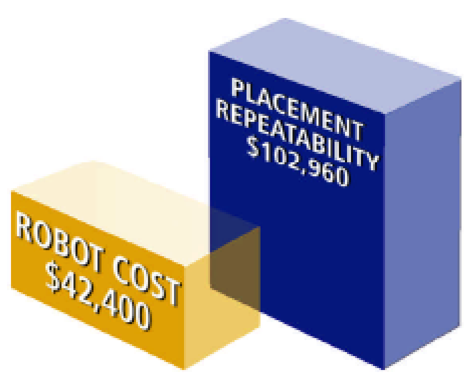
Labor	$640	($80/Hour X 8 Hours)
Chamber Downtime	$2,000	($250/Hour X 8 Hours)
Weekly Cost	$1,980	($2,640 per week X 75%)
Yearly Cost	$102,960	($137,280 per year X 75%)

Assumes that only one chamber is down during maintenance.

Table 3
Comparison of Backlash on OEM Robot vs. Fabworx Robot



ONE-YEAR ROI



RETURN ON INVESTMENT	
ONE-YEAR ROI	242% ($102,960)
PAYBACK INTERVAL	21.4 weeks

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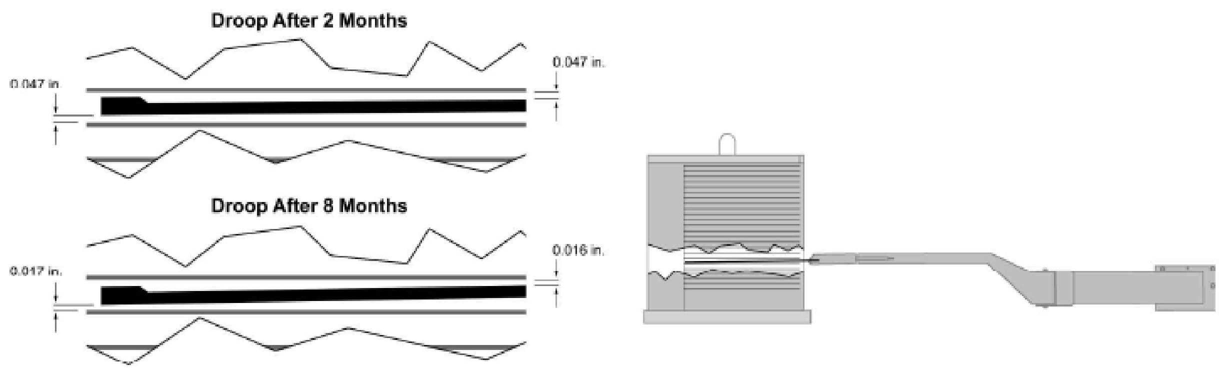
Financial Implications of Robot-Related Wafer Scratches

Problem
Many fabs report blade-related wafer scratches to be one of their largest sources of yield loss. When scratching occurs, the probability of defect die is nearly 100%. Blade-related wafer scratches occur when the robot directly contacts the topside of a wafer, while extending into the cassette to either extract or return a wafer located in the slot above. The dominant cause of blade-related wafer scratching is robot droop.

Droop occurs naturally, as the robot ages and wears. As droop worsens, the robot blade uses more of the vertical clearance area between wafers within the cassette (see Figure 3). While much of this area is already used by the blade thickness, additional space is required when robot droop is considered. As blade-to-pitch clearance becomes smaller, wafer scratches resulting from droop become more likely. Due to design and wear issues, droop is unavoidable in the OEM robot design.

Figure 3
OEM Robot Blade-to-Pitch Degradation After 2 and 8 Months (200 mm Wafers)

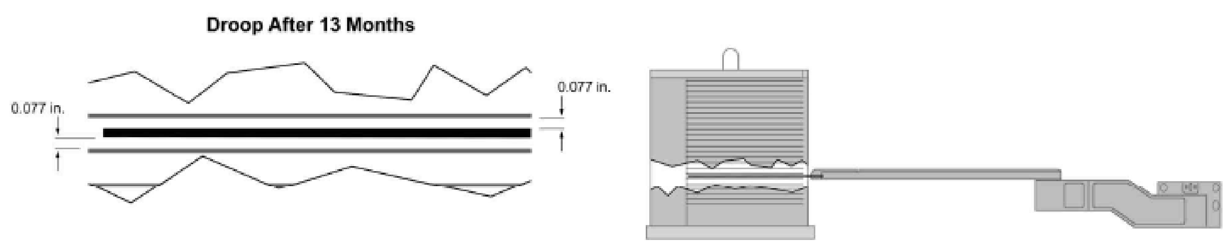


Solution
Blade-related wafer scratching is virtually eliminated in the Fabworx robot, via three design enhancements:

- Overall design is more structurally rigid, using stronger materials, stiffer springs and tighter tolerances, eliminating any measurable droop.
- The robot provides fine-tune adjustment during setup, for greater precision.
- Blade thickness (0.090 in.) is thinner than the OEM blade (0.120 in.), resulting in more vertical space between wafers within the cassette (an additional 0.030 in.).

While Figure 3 reveals significant droop degradation in the OEM robot over eight months, Figure 4 shows no measurable droop in the Fabworx Robot over a period of 13 months. Vertical clearance area is also larger, due to the blade's thinner profile.

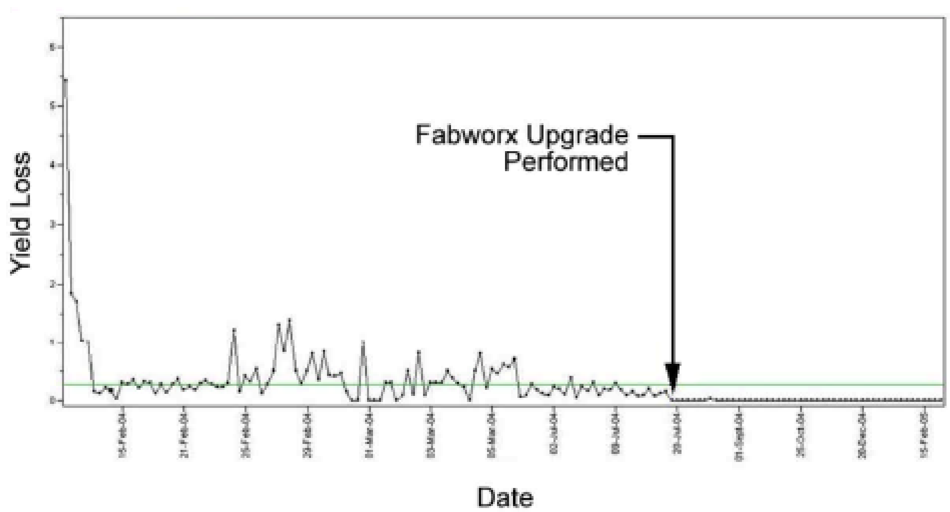
Figure 4
Fabworx Robot Blade-to-Pitch Spacing after 13 Months (200 mm Wafers)



Customer Data

One customer encountered periodic wafer scratching resulting from the OEM robot's blade at a particular process step. This phenomenon occurred consistently over several months (Figure 5). Detailed data-mining capability was used to extract tool-induced scratches from other yield-limiting events, and long-term yield loss attributable to blade-related scratching was 0.34%. A Fabworx upgrade was performed, eliminating this problem: subsequent blade-related wafer-scratch yield loss was zero.

Figure 5
Yield Loss Due to Blade-Related Wafer Scratching, Before and After Fabworx Upgrade

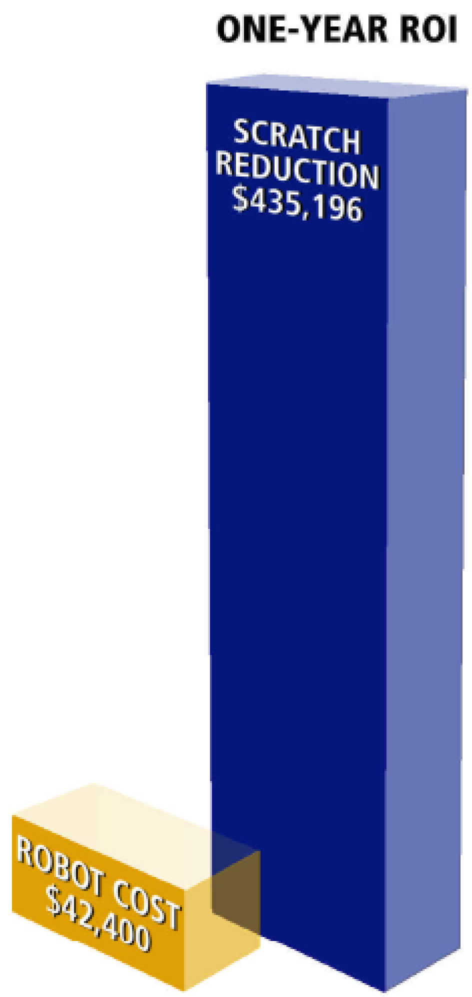


Calculation

A before-and-after analysis was generated using different tool-yield numbers. As expected, small yield differences provided large changes in COO.

While the customer data shown in Figure 5 reveals a yield gain of 0.34%, a more conservative gain of 0.2% is used to calculate ROI. Inserting this 0.2% yield change into the model provides a cost-per-wafer of $5.81, versus a baseline of $4.01; the result is a difference of $1.80 per wafer.

At normal operating speeds, the Fabworx-upgraded tool will process 241,776 wafers per year ([40 wafers/hr. X 24 hrs./day X 365 days/yr.] X 69% OEE). When multiplied by the cost-per-wafer difference of $1.80, an annual savings of $435,196 results.



RETURN ON INVESTMENT

ONE-YEAR ROI	1026% ($435,196)
PAYBACK INTERVAL	5 weeks

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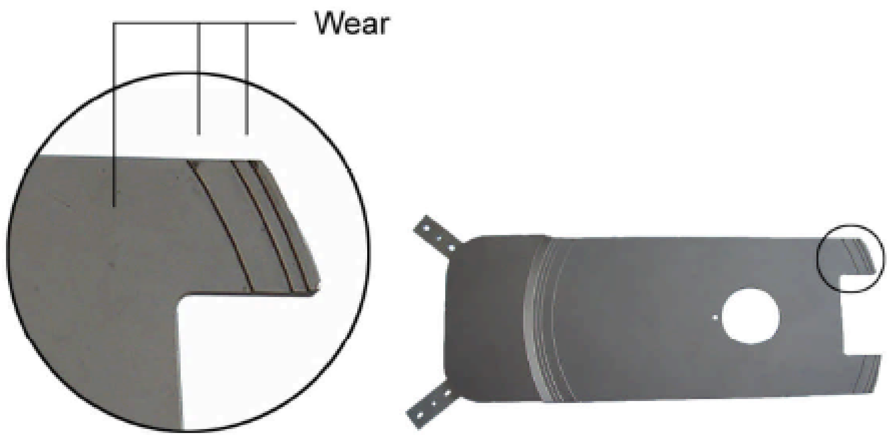
Financial Implications of Robot-Related Particles

Problem
Three issues result in particle contamination with the OEM robot:

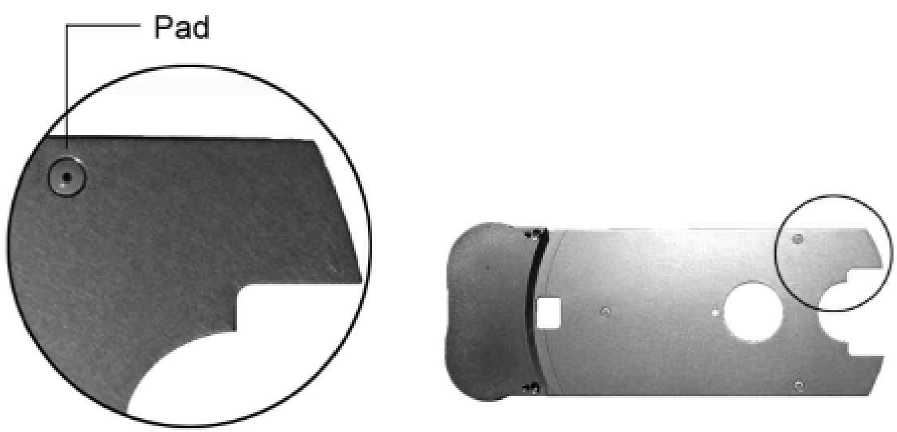
- Aluminum and nickel particles are generated from wafer movement within the pocket of the blade (Figure 6).
- Wrist bearings are exposed and wear quickly, leaving behind ferrous particles in the wafer environment. Hub bearings also wear quickly, generating ferrous particles.
- An excessive amount of bearing grease is required, generating additional contaminants.

Figure 6
Wear on the Surface of the OEM Blade, Resulting from Wafer Movement



Solution
- The Fabworx robot employs ceramic bearings to provide long life and ball separators to further reduce wear.
- Wrist and elbow bearings are sealed and a small amount of high-quality, high-vacuum lubricant is used.
- A wafer pocket is not used; wafers rest on three perflouroelastomer pads (Figure 7) with a high coefficient of friction. Wafer sliding is eliminated, along with associated particles.

Figure 7
Pads on Fabworx Robot Blade



Customer Data
Several customers have validated the particle-reduction benefit of this Fabworx upgrade. Figure 8 shows the defect density of eight tools, measured over a nine-month period. During the fifth month of data collection, two of the tools were upgraded to a Fabworx Robot. (While the data shows a non-related process issue during month six, defect density levels returned to nominal when this issue was resolved during month seven.) A substantial particle decrease resulted in those tools with the Fabworx upgrade.

Wafer backside particles create their own problems. Table 4 shows wafer backside particle data collected on another customer tool, before and after the Fabworx Robot was installed.

Calculation
While the effects of particle contamination vary at each step throughout the fab, the resulting benefit of reduced particles is increased yield. In general, the ROI impact of a yield increase is quite large. While some customers

Figure 8
Defect Density of Several Tools Over Nine Months

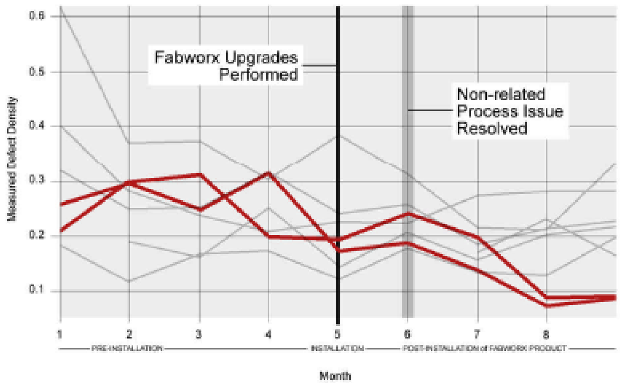


Table 4
Wafer Backside Particle Defects, Before and After Upgrade

Particle Size	OEM Blade	Fabworx Blade
0.16 - 0.26 µm	126	26
0.26 - 1.0 µm	79	18
1.0 - 2.0 µm	10	0
Area Defects	32	18

reported yield increases in the range of 4-6% due to the Fabworx upgrade, a conservative increase of 0.4% is used to calculate ROI.

The model was run using a baseline OEM configuration, resulting in a cost per wafer of $4.01. When the tool-yield parameter is changed by 0.4%, the resulting cost per wafer increases to $7.63.

At normal operating speeds, the Fabworx-upgraded tool will process 241,776 wafers per year ([40 wafers/hr. X 24 hrs./day X 365 days/yr.] X 69% OEE). When multiplied by the cost-per-wafer difference of $3.62, an annual savings of $875,229 results.

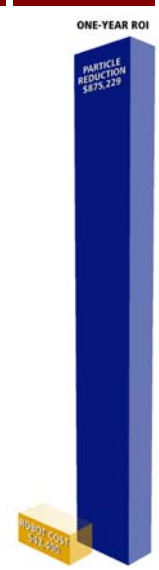
Table 5 further demonstrates the ROI potential of the Fabworx upgrade. These minor yield losses from basic deficiencies in the OEM robot dramatically affect the economics of the tool. Depending on the fab's level of robot-induced defectivity, the payback of performing a Fabworx upgrade is nearly immediate.

Table 5
Fabworx Yield Improvement vs. ROI and Payback Interval

Robot-Induced Yield Loss	0.25%	0.50%	0.75%	1.00%	1.25%	1.50%
Change in Cost Per Wafer	$1.27	$4.55	$6.83	$9.13	$11.45	$13.47
One-Year ROI	**$307,055**	**$1,100,080**	**$1,651,330**	**$2,207,414**	**$2,768,335**	**$3,256,722**
Payback Interval (DAYS)	**50**	**14**	**9**	**7**	**6**	**5**

RETURN ON INVESTMENT

ONE-YEAR ROI	2064% ($875,229)
PAYBACK INTERVAL	< 3 weeks



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Summary

Five performance areas were examined during this analysis, in which OEM issues and potential improvements to each were reviewed. WWK's TWO COOL software application was used to determine the financial implications of the design enhancements provided via the Fabworx upgrade. Both COO and ROI were modeled using before-and-after data supplied by customers. To remain conservative in the modeling calculations, a lesser improvement than what was actually achieved was used to determine ROI.

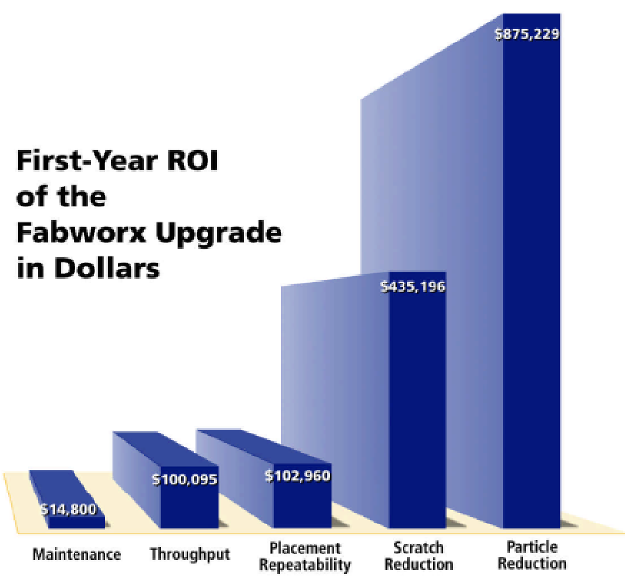
The TWO COOL software proved highly effective at providing the information of interest. The software was easy to use, was exceptionally flexible, and had the capabilities required to analyze the financial implications of this robot upgrade.

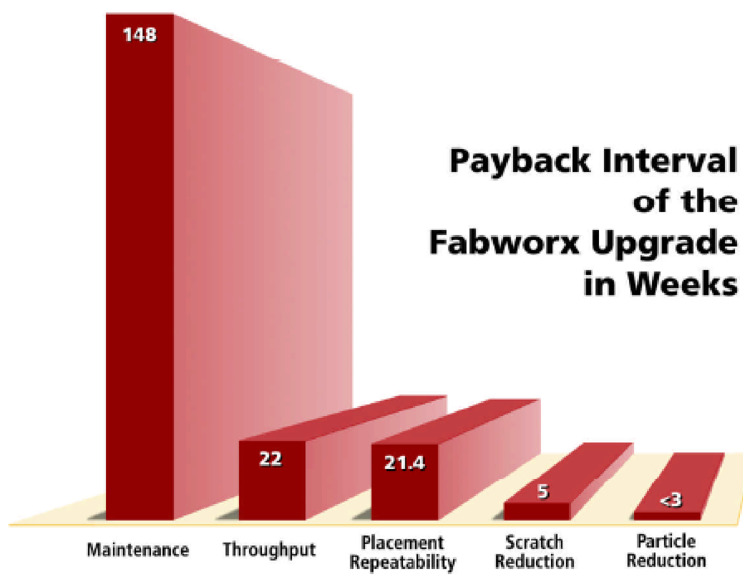
The Fabworx Solutions Robot demonstrated considerable financial benefit to those customers who provided the data used in this model. Several improvements were evident in the Centura and Endura tools as a result of the Fabworx upgrade. All areas demonstrated a strong return on investment.

The five performance areas that were modeled are summarized on the right side of this page.

- As expected, improvements made to the tool for basic parts reliability reasons (i.e., bearing replacements) have a moderate ROI, with a payback period of over two years.
- Improvements in tool productivity, allowing higher throughput or more uptime, have a much better ROI and a payback period of roughly six months.
- Scratches and particles impacted yield the most. The associated payback from these improvements is extremely large. The one-year return is 10 to 20 times the investment, and payback occurs in a few weeks.

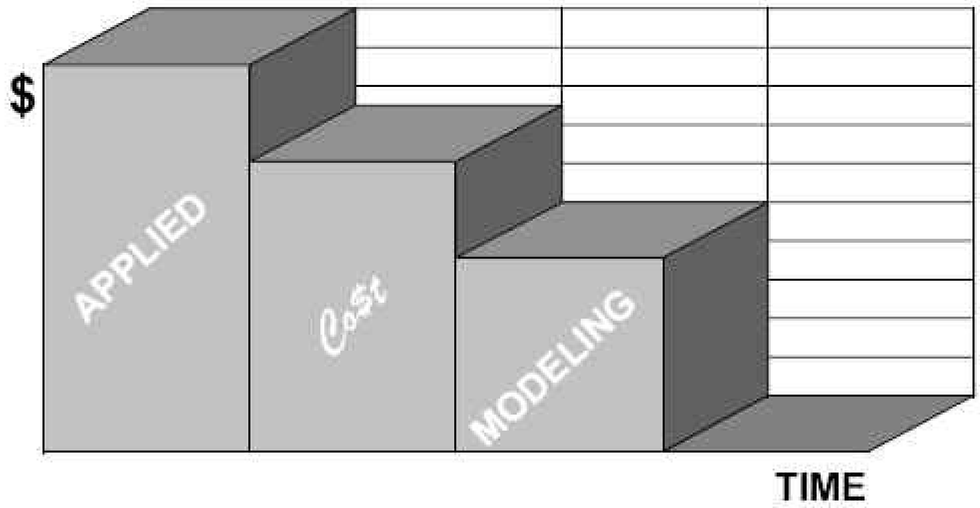
Given the current industry financial pressures, the ability to analyze in detail the benefit of both tool and tool upgrade purchases is exceptionally valuable. Smart deployment of limited capital is a must. WWK software helps fabs make these difficult decisions. The Fabworx Solutions Robot helps fabs achieve the best performance possible from their existing equipment. Return on investment of these upgrades is substantial.





About Fabworx Solutions

Fabworx Solutions, Inc. designs and manufactures upgrades for semiconductor manufacturing equipment. Their flagship series of products focuses on mechanical robot arm upgrades for HP and VHP robots on both Endura and Centura platforms. Other products include End Effectors and Wafer Handler Picks for a variety of other semiconductor manufacturing tools. Design features dramatically improve reliability, contamination control, repeatability and throughput of these systems. Headquartered in New Hampshire, Fabworx Solutions products are installed in leading fabs throughout the world. Information can be found on the web at fabworx.com, or by phone at 603.938.5658.



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