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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 begin a new series on mask defect inspection strategies. Those interested in the cost of ownership 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

Background

Incoming mask inspections as well as periodic mask inspections (requalification) in advanced wafer fabs are a necessity to prevent yield loss from progressive mask defect problems (such as crystal growth or haze), traditional reticle contamination, electrostatic discharge (ESD), and migrating defects (from noncritical to critical location on mask). This mask inspection can be achieved by two methods. The first method is indirect-commonly known as image qualification-where a mask is being exposed followed by the inspection of the printed wafer to detect if there are any repeating defects on the wafer. The other method of mask inspection is direct mask inspection.[1]

[Continued on page 3]

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[1] A Cost Model Comparing Image Qualification and Direct Mask Inspection, Bhattacharyya et al, Photomask Technology 2006

Editorial Board

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Calendar of Events

March 2011

28-31 NA Standards Spring Meetings
SEMI Headquarters
San Jose, CA

28 Cost of Ownership Task Force Meeting
SEMI Headquarters (1-4pm)
San Jose, CA

April 2011

15-17 PV America
Pennsylvania Convention Center
Philadelphia, PA

May 2011

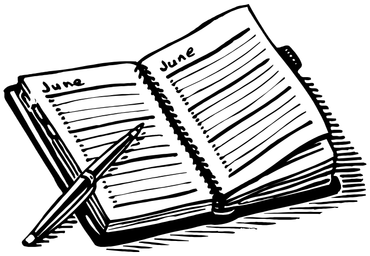
11-13 SEMICON Singapore
Suntec Convention Center
Singapore

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



This report examines image qualification on test wafers and direct mask inspection. The data used in this report consists of litho cluster data previously developed by Wright Williams & Kelly, Inc. (WWK) and publicly published data regarding inspection strategies and costs including the above referenced paper. WWK has taken the data and strategies and extended them to examine the cost structures of these competing approaches well beyond the work previously done. This report has been funded by WWK and was not influenced by outside entities with vested interests in capital equipment sales. As such, WWK has examined various scenarios that fabs face on a daily basis. As expected, each of these approaches has merit; the question is how the cost structures change based on the operating conditions of the fab.

Cost of Ownership Defined

SEMI E35 defines cost of ownership (COO) as the full cost of embedding, operating, and decommissioning, in a factory environment, a system needed to accommodate a required volume of units (e.g., wafers). The significant COO inputs include:

- Equipment cost
- Operating cost
- Yield
- Utilization
- Throughput rate

These factors are combined in the COO equation:

$$COO = \frac{F + R + S}{L \times TP \times TU \times PRY} \quad [2]$$

where:
COO = Cost of Ownership,
F = Sum of all fixed costs over the life of the equipment,
R = Sum of all recurring costs over the life of the equipment,
S = Sum of all scrap costs over the life of the equipment,
L = Lifetime of equipment (years),
TP = Throughput of equipment (units/year),
TU = Total utilization, and
PRY = Product yield.

Fixed costs are incurred once during the lifetime of equipment and are associated with the acquisition and installation of equipment. Fixed costs include costs such as equipment purchase, installation and setup, facility modifications, initial training, and initial qualification costs. Recurring costs are incurred on an on-going basis. Recurring costs such as material, labor, repair, standards, requalification, utility, and overhead expenses are costs that are incurred during equipment operation. Cost of yield loss is the value of scrap caused by the process step. Process scrap identified at the step of interest but caused by prior processing is part of the prior process step COO. Thus, yield losses caused by the processing equipment must be clearly separated from prior losses. The sum of these costs form the numerator of the COO equation.

The denominator of the COO equation is an estimate of the number of good units produced during the lifetime of equipment. Throughput rate is based on process and handling times such as job setup, loading and unloading, reporting, and other overhead operations. It excludes training, repair, and qualification times since these are included in utilization. Yield may be defined as the ratio of good units compared to the total number of units produced. Utilization is the ratio of actual productive usage time compared to total time. Utilization includes the effect of repair and maintenance time, both scheduled and

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[2] From proposed update to SEMI E35-0307

unscheduled, setup and qualification time, standby time, engineering time, and nonscheduled time. It shows the impact of nonproductive time on cost and normalizes ideal throughput to a realistic estimate. Utilization is estimated using SEMI E10 definitions for equipment state times and total utilization.

Cost of Ownership Overview and Methodology

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

For the following analyses, 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.

Direct Mask Inspection 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 was used for both direct mask and image qualification scenarios. Table 2 data was used as the base case for direct mask inspection. 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 direct mask inspection are listed below in Report 1. While this data is really only useful when compared to the results for image qualification, 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 1 value a productive minute at $98.53, which agrees to within 20%. This value will be reexamined in the section on image qualification which is a more direct comparison to the $500 results previously cited. 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 cluster 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. Of course, DRAM and Flash would have longer usage and pure ASIC would have shorter.

Table 1: General COO Assumptions

Litho Cluster	
Throughput	136 wafers per hour
Equipment Set Volume Requirement	80,000 wafer passes per week
Number of Clusters Needed	5
Cluster Cost	$25,000,000
Mask Cost	$75,000
Mask Life (damage, redesign, etc.)	2,000 wafers

Table 2: Direct Mask Inspection COO Assumptions

Direct Mask Inspection	
Litho Cell Availability Impact	none
Yield Loss	none
Mask Inspection Cost	$632
Mask Inspection Frequency	1,000 wafer passes
Back Up Masks Needed	none

Report 1: Direct Mask Inspection 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	87.10	Percent
Composite Yield	100.00	Percent
Good Wafer Equivalents Out Per Week	80,000.00	G.W.E.'s
Good Wafer Equivalent Cost		
With Scrap	54.06	Dollars
Without Scrap	54.06	Dollars
Average Monthly Cost		
With Scrap	18,793,782	Dollars
Without Scrap	18,793,782	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)	136,553,421	Dollars
Per Good Wafer Equivalent	4.68	Dollars
Per Good cm2 Out	0.0083	Dollars
Recurring Costs (Over Life of Equipment)	1,442,124,305	Dollars
Per Good Wafer Equivalent	49.39	Dollars
Per Good cm2 Out	0.0873	Dollars
Total Costs (Over Life of Equipment)	1,578,677,726	Dollars
Per Good Wafer Equivalent (Cost Of Ownership)	**54.06**	**Dollars**
Per Good Wafer Equivalent Supported	54.06	Dollars
Per Good cm2 Out	0.0956	Dollars
Per Productive Minute	98.53	Dollars

One assumption of the direct mask inspection model described above is that it has no impact on litho cluster availability. While it is true that direct mask inspection does not impact production qualification time, it is not so clear that the removal of the mask can be done without interrupting the scanner. Based on the COO results above, the cost for lost production time for mask transfer is $98.53 per minute lost. At approximately two mask transfers per day per litho cluster, the cost impact is approximately $0.10 per wafer pass per minute of lost production time.

A more important factor for examination is the potential need for additional mask sets. While this can be a very complex decision based on the total number of mask sets already assigned to the scanners and the flexibility of the lot dispatching system, a decision must be made to either allow lots to sit idle for some period of time while the mask is being inspected or to buy additional mask sets to allow for mask rotation in and out of production.

As can be seen in Chart 1, the number of additional masks needed to support direct mask inspection can be significant. The increments in the chart represent cost allocated to each litho cluster based on a specific sharing scenario with $15,000 representing a single $75,000 mask shared among all 5 litho clusters. If a back up mask is needed for each litho cluster, the COO increases by nearly 80%. This indicates that mask costs, assuming 2,000 wafer pass life, is far more important than even the $25M capital cost.

Chart 2 assumes one extra mask is needed and it is shared between all five litho clusters ($15,000). This sensitivity analysis varies the mask life from 1,000 wafers to 20,000 wafers. The base model assumption was 2,000 wafers which is on the steeply sloped region of the curve. The same life was also applied to the mask under inspection.

Chart 3 examines the same data as Chart 1 but at a mask life of 10,000 wafers. The results show a factor of 3 improvement in COO at the base assumption of one extra mask shared between all 5 litho clusters. These charts clearly show that the cost effectiveness of direct mask inspection is dominated by issues of mask inventory and useful life.

The next edition of Applied Cost Modeling will continue with Direct Mask Inspection Cost Validation and Image Qualification Impacts on Litho Cluster COO.

Chart 1: Sensitivity Analysis, Mask Inventory (2K Life)

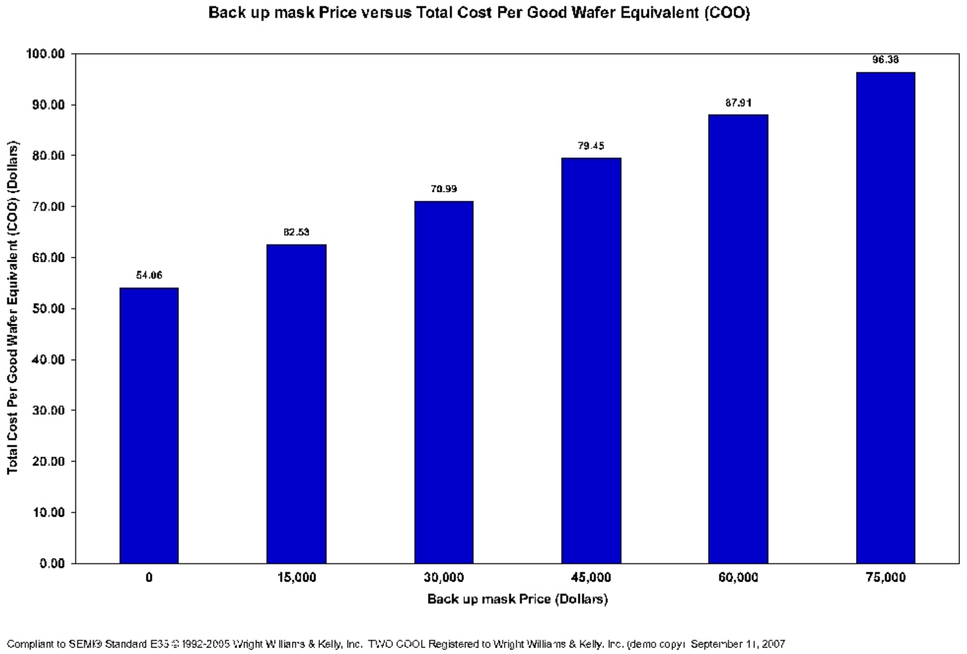


Chart 2: Sensitivity Analysis, Mask Life

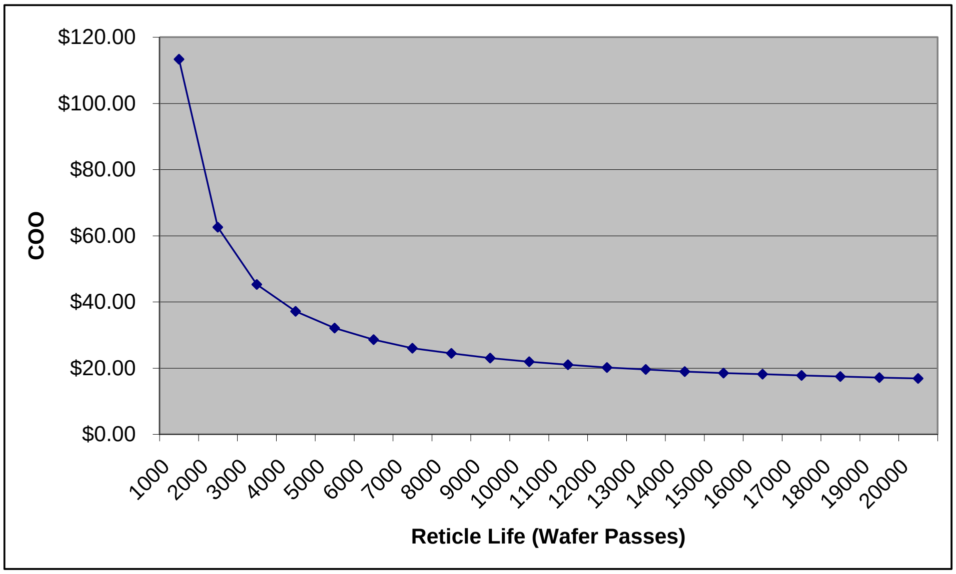
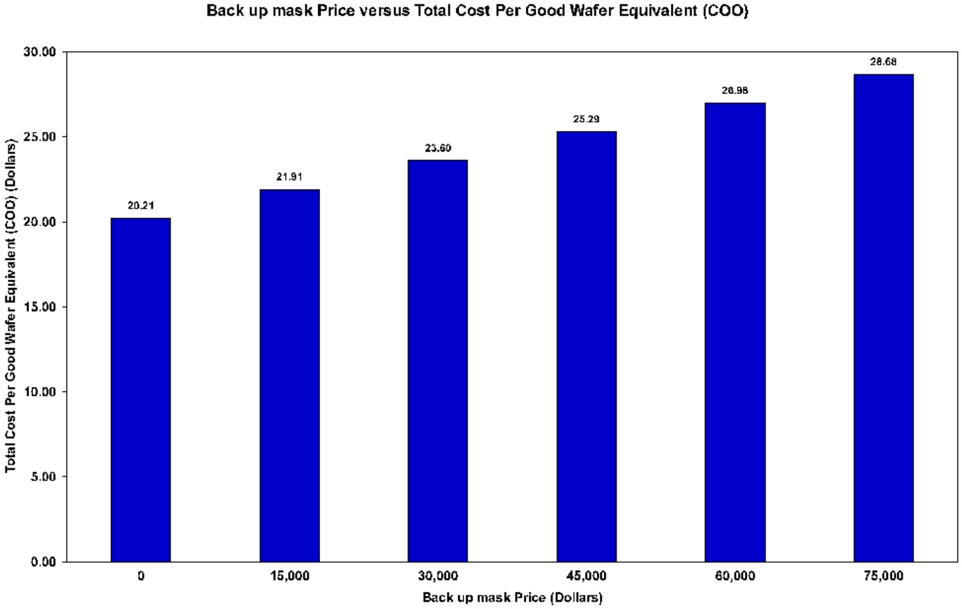


Chart 3: Sensitivity Analysis, Mask Inventory (10K Life)



Compliant to SEMI© Standard E35 © 1992-2005 Wright Williams & Kelly, Inc. TWO COOL Registered to Wright Williams & Kelly, Inc. (demo copy) September 11, 2007

Wright Williams & Kelly, Inc. Conducts 5th Annual Semiconductor Manufacturing Technology Survey

Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today the start of its 2011 survey on equipment and process timing in the semiconductor industry. The survey results will be consolidated and provided to all participants free of charge. Participation in the survey is the only way to receive a full set of results. The survey form can be downloaded from the WWK web site at: http://www.wwk.com/2011survey.pdf.

Last year's survey showed that respondents expect to see the following manufacturing technologies in production by 2011:

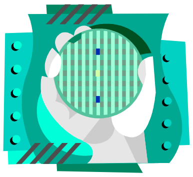
- Double patterning
- Through Silicon Vias (TSV)
- Equipment suppliers using remote diagnostic capability
- Manufacturing capacity, utilization, and cycle time simulation
- Implementation of 300mm prime advances

However, survey respondents did not expect to see the following technologies in production until 2015 or beyond:

- 193 high-index immersion lithography
- Direct write
- EUV lithography
- Imprint lithography

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), and 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 record 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 COO and 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.



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. At this time, registration for this seminar can only be done by calling WWK directly.

There is limited seating available for this seminar, so please contact WWK today to guarantee your place in this once-a-year event. 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.

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Accelerating the Movement to Grid Parity in Photovoltaic Manufacturing

Alan Levine, Wright Williams & Kelly, Inc., Pleasanton, CA

First the good news; the photovolatics (PV) industry is maturing. Fortunately for us, our cousins have broken a lot of useful ground. The integrated circuit (IC) industry has provided insights about how to grow, handle, and process silicon. The flat panel display (FPD) industry has provided us information about how to handle and process large, delicate substrates.

While many see the IC industry as the closest to the PV industry, it actually mimics the FPD industry more. FPD processes are shorter and more linear than IC processes, with limited re-entrant flows. The processing is high volume, high speed, and much less defect sensitive than ICs. There is much less differentiation among products and the capital costs for a facility are similar in magnitude. Perhaps most importantly, there is a clear economic hurdle from an established technology that must be overcome in order to capture significant market share.

In the display world, FPDs had to overcome the incumbent cathode ray tube (CRT). The ability to lower manufacturing costs enabled FPD prices to drop sufficiently and opened the door to several niche applications. Getting there was no easy task. It involved smart choices on cost effective manufacturing while concurrently meeting key performance criteria. After decades of development, FPD found a key niche in laptops. Companies saw positive returns on a large enough scale to warrant major investments into new markets. In virtually every segment of FPD, manufacturing efficiency has been the key in transitioning from a niche supplier to a dominant market share position.

The PV world's version of the CRT is called grid parity. As with the CRT, grid parity is not a single number, but an array of numbers based on several factors. Each time grid parity is achieved for a niche, the PV market grows. Achieve grid parity with the mainstream power generation techniques and the world changes.

When we accelerate the PV industry on the path towards grid parity, we open new markets, improve profits and create the momentum that allows for greater opportunity. So how do we accelerate ourselves along this path?

Grid parity is not easily achieved. Volume alone will not get us there. The quickest way to achieve grid parity is to use our resources wisely. What does this mean? It means innovation and operations must be tied to value. The tools that connect technology to value are known as operational models. Operational models mimic the operation (i.e., a factory, a business, a process), in whole or part, in order to assess whether the path the organization is on (e.g., road maps, developments) will achieve the desired results. The concepts are tested in software to determine the payback, allowing smart choices to be made about the next steps for the business. At the core of operational modeling is one simple principle: every decision, even a decision that appears technical, is a business decision.

The tools that were developed to analyze the IC and FPD industries were, and continue to be, enabling technologies for these industries. The tools, such as cost of ownership (COO), cost & resource modeling, and discrete-event simulation, have resulted in massive improvements in cost and performance. These tools are available to the PV industry, and they work beautifully. The underlying standards developed by Semiconductor Equipment and Materials International (SEMI) ported over to the FPD world seamlessly and they also port over to the PV world. The methods that allow information to be analyzed are common to ICs, FPDs, magnetic heads, crystal growing, PV cells, PV modules, and thin film panels. These are solved problems. Nonetheless, the PV industry has been reluctant to embrace these tools. While our relatives have done graduate work in these areas, the PV world is, by and large, still working on Factory Productivity 101.

The power of operational modeling can be seen from the smallest changes, such as a modest change at a specific process step, all the way to looking at multiple factories running multiple products in multiple locations around the world.

Let’s start with a few cautionary notes about common methods employed currently. Intuition does not work well when more than a few variables are in play. Most analyses are laden with subtleties. Single-product factories quickly become multi-product factories with embedded development lines. Companies are constantly ramping products up and down. One company might adopt cash flow as the most critical metric, another company might choose internal rate of return (IRR). Quick and dirty spreadsheets used for simplified ‘greenfield’ situations have proven woefully inadequate in real world situations.

Suppliers occasionally offer a cost analysis to prospective clients, but typically show only what helps them the most. Manufacturers are often just as bad. One client told us that every person that did cost analysis in their operation had their own unique way of doing it. The silver lining was the recognition that cost analysis mattered.

Still, cost is only a modest part of the drive to lower cost per watt. Value is an integral part of the equation. Among PV suppliers and manufacturers, it is rare to find the ability to analyze cost and value concurrently.

Using a simple concept to illustrate the way forward; let’s look at changing a material at a specific process step. How does this change the cost? There are several possibilities. The material itself has a cost. The material may impact the equipment it is used on in several ways, such as reliability, preventive maintenance, or throughput. It may impact other materials or waste disposal. It may impact multiple processes, not merely the one process where the material is used. Some of these impacts, such as a change in equipment productivity can change the factory physics. It may impact yield, the value of the finished unit, and even the probability of a failure in the field. One modest change can have a large number of impacts.

In practice, while it is possible to model everything, most decisions require far less rigor.

When a potential change is identified, the next step is to determine the areas of potentially significant impact. This is key. There is a tendency to limit the analysis to areas where it is easy to gather data, while avoiding what might be more challenging or time consuming areas of data collection/analysis. This is where we find out if management is serious about optimizing the business, since several things become apparent rather quickly. Does management provide adequate time to do a proper analysis? Are the necessary resources, tools and/or experts, available to do the analysis? Are data sets readily available that allow the analysis to be performed more efficiently?

In our experience, technologists and engineers do not spend time calling the finance department to get burdened labor rates; nor should they. In practice, much of the information required to do an analysis is readily available, but a person is unlikely to get the information if it requires them to go to 15 different places to chase it down. Creating the infrastructure to do the analysis work is low in cost and technically straightforward. The major ‘problem’ is rather subtle. The input information cuts across functional lines within the organization, meaning a buy-in must happen across the operation. This broad ‘buy-in’ can create difficulties, even if the technical issues are very modest. In practice, this ‘buy-in’ happens readily when the edict comes from the person at the top of the organizational chart.

The proper use of operational models involves determining the right set of items to consider, not merely what is easiest. This is done by using a list of questions to guide the user in setting up the analysis. In the previous example, one question is, “What other process steps might change based on the original change?”

Once the set of questions has been developed, the next step is to determine the appropriate analysis tool. To analyze a process step, where the issues are essentially self-contained within the step, COO is a very effective tool. To look at sequences that are self-contained, a different form of COO can be used. The COO example in Figure 1 is for a single step. It shows how a sophisticated approach, incorporating continuous improvement, makes a major difference in determining the costs of the operation.

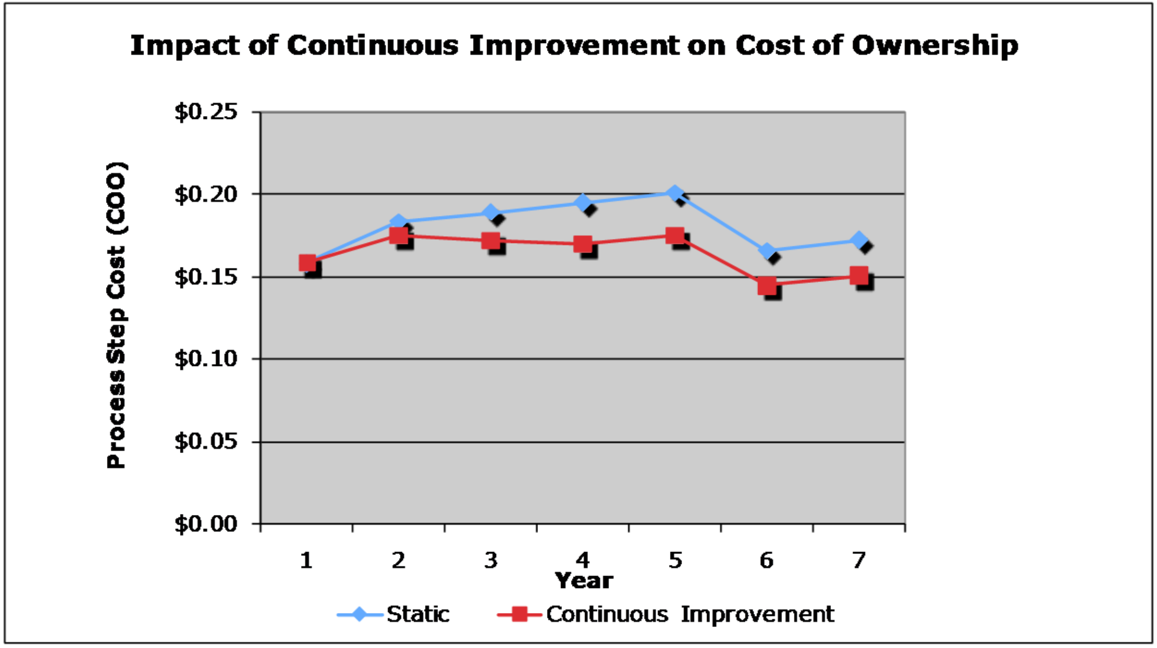

Figure 1: Continuous Improvement Driven by COO Methodologies

Using the continuous improvement capability in TWO COOL®[1] allows COO to be examined in a realistic manner. In this example, inflation drives labor and material costs up, while improvements in raw throughput, reliability and test times drive costs down. Continuous improvement provides a COO benefit of about 5% in year 2 and increases to about 14% beginning in year 4.

Once value enters the equation, often in the form of a change in selling price, COO can no longer capture the monetary benefits. At this point, cost & resource modeling takes over. Of note, COO is a subset of cost & resource modeling. Cost & resource modeling looks at the operation as a whole. Often, decisions can be made with subsets of information. If there is a single principle in dealing with models, it is to make them useful, not perfect. By looking at the entire operation, a wide array of potential questions can be answered:

- Will the enterprise make a profit?
- How many people are needed?
- What is the cash flow?
- When to ramp one product down and another up?
- Where to build a new product?
- Should the organization build or outsource?

These decisions can be either tactical or strategic. In either case, modeling provides objectivity, which improves the quality of the decision. The example in Figure 2 shows how product costs change as the factory ramps up some products and ramps down others.

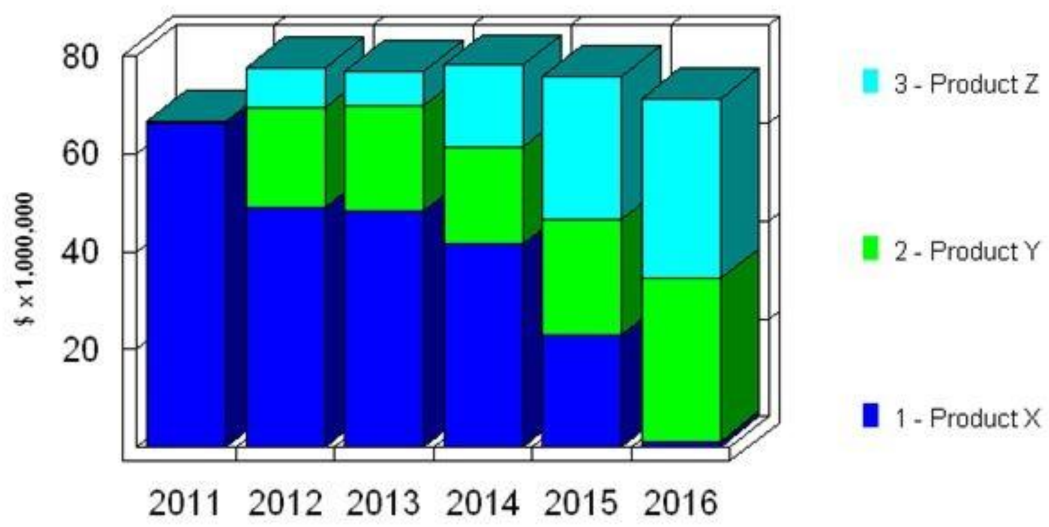

Figure 2: Total Annual Cost, by Product, in a Multi-Product Factory

Projecting total product costs is critical to driving high ROIs. Here, an output from Factory Commander®[1] shows the evolution from a single-product factory in the first year to a multi-product factory in subsequent years. The change in total costs reflects the changing costs and volume for each individual product.

There is another element that impacts the relentless drive to improve productivity, factory physics. Factory physics is a broad term used to describe how the operation behaves. In practice, the interactions of complex processes, queues, and reliability can have substantial impacts on the productivity of a factory. While there are many aspects to this, the most critical issue typically revolves around optimizing the bottleneck resource. A well-designed operation will usually have the most expensive capital equipment set be the bottleneck. The challenge is to insure the bottleneck is fed with production units 100% of the time it is available. Any idle time lost at a bottleneck translates to lost capacity for the entire factory. This is what differentiates a bottleneck process or equipment from other processes.

Bottleneck analysis gets complex very quickly. For example, take a situation where two products are run through a nonbottleneck operation. The operation for the first product runs slowly, but the operation for the second product runs quickly. If there is a change in the product mix that increases the demand for the first product, the nonbottleneck operation can suddenly become a bottleneck. In practice, there are many items that impact factory physics.

In order to accurately address bottleneck management, a technique called discrete-event simulation is employed. This technique allows companies to see the interactive effects of a very wide array of factors. Often, the challenge in managing a bottleneck resource is driven by an understanding of the variability in reliability of prior steps.

Even when resource availability is highly predictable, it can be a challenge to optimize the factory. For example, preventive maintenance (PM) is highly predictable. Optimizing PMs, especially between linked systems, can be difficult. One step may require a cleaning every 1,000 units, another may require a recalibration every 4 hours, and a third may need a conditioning process with every 100µm of deposition.

However challenging the PM schedules are, addressing the variability in reliability is the tougher task. This is not just reliability at the bottleneck, but reliability at other process steps that impact the bottleneck. Further complicating the situation is the availability of the resources needed to fix down equipment, both people and parts. People have a big impact on downtime characteristics. Cross training of maintenance staff can be a powerful way to improve bottleneck productivity. Another powerful method is to determine an optimal set of dispatch rules for each process. However, the rules are rarely intuitive and the number of variations can be quasi-infinite. Discrete-event simulation is the best way to look at a large variety of rule combinations in a very short time frame. Factors like intelligent cross training and an optimal set of dispatch rules can achieve capacity increases of 10%-20%, even in seemingly well-run operations. (see Figure 3)

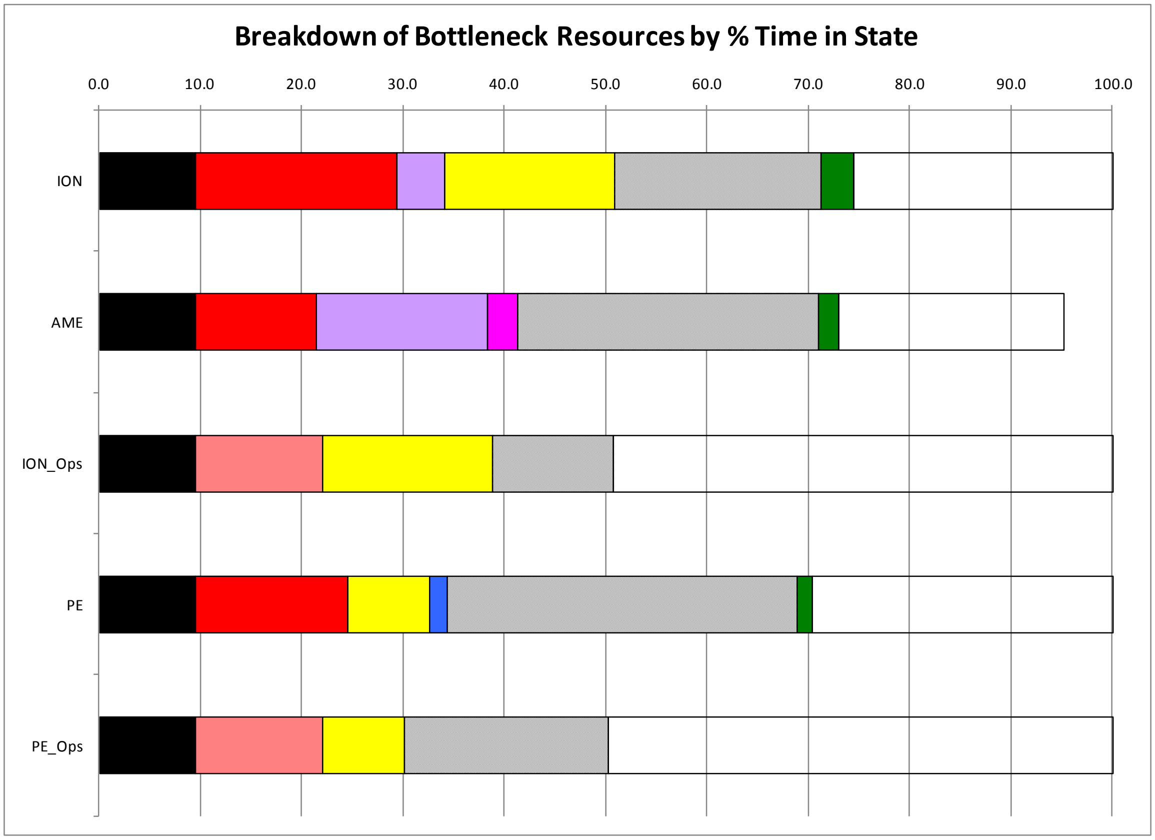

Figure 3: Operational States of Bottleneck Resources

Factory Explorer®[1] and its discrete-event simulation engine create a detailed understanding of the constraints on the factory. In the above figure, five resource sets are analyzed for potential bottleneck situations, three equipment sets (ION, AME and PE) and two operator sets (ION_Ops and PE_Ops). The colors represent the percentage of time a resource is in a given state (e.g., PM, unscheduled downtime, set-up time, processing). Analyzing bottlenecks is necessary to determine the highest payback when allocating resources.

Technologists try to optimize things like surface reflectivity, uptime, and uniformity; but in reality, it comes down to needing to optimize money. If technical decisions are not tied to money, almost certainly resources are not being employed wisely. The challenge for companies in the PV industry is to form a bridge between technology, operations, and business. The methods for doing this have been pioneered by related industries. The solutions are out there. Invest in them and your business will have a sustainable competitive advantage.

References

1. TWO COOL®, Factory Commander®, and Factory Explorer® are commercial software packages from Wright Williams & Kelly, Inc. (www.wwk.com).

Hi-Tech Equipment Reliability
A Practical Guide for Engineers and the Engineering Manager

By Dr. Vallabh H. Dhudshia
Reprinted by Permission of the Author

High-Tech Equipment Reliability Series

WWK recently received permission to reprint sections from Dr. Vallabh H. Dhudshia's book, Hi-Tech Equipment Reliability: A Practical Guide for Engineers and Managers. This book, first published in 1995, is now back in print:

http://www.amazon.com/exec/obidos/ASIN/0595458289/wrighwillikelly

Dr. Dhudshia has been an equipment reliability specialist with Texas Instruments and with Xerox Corporation. He served as a Texas Instruments assignee at SEMATECH for three years. Dr. Dhudshia received a Ph.D. in IE/OR from New York University. He is an ASQ fellow and a senior member of ASME. He has developed and taught courses in equipment reliability overview and design practices. He is an affiliate of WWK, specializing in reliability consulting.

In the last issue of Applied Cost Modeling we reprinted Chapter 14. If you are interested in the remaining chapters, please use the above link to order your copy.