Information Exchange For Your Application & Use of Cost Modeling

APPLIED Co$t MODELING

Volume 10. Issue 3

Inside

Spring 2004

ISSN 1094-9739

APPLIED RESEARCH ACTIVITIES IN COST ANALYSIS FOR ENVIRONMENT, SAFETY, AND HEALTH

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Abstract

Since costs associated with environmental, safety and health (ESH) can significantly increase semiconductor manufacturing costs, ESH costs need to be accounted for and linked with manufacturing process activities. Since accounting for ESH costs is not often part of a management information system, many critical ESH business and operating decisions are made without understanding the total economic impact. This paper will summarize a joint applied research effort by SEMATECH, Oregon State University, and Wright Williams & Kelly to model ESH costs associated with the equipment and process life cycles in the semiconductor industry.

Introduction

The semiconductor industry traditionally focuses on cost, yield, and logistics in making process and equipment

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Editorial Board

Publisher

Published quarterly by:

Wright Williams & Kelly, Inc.
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Calendar of Events

June

1-4 **IEEE 54th Electronic Components & Technology Conference**
Las Vegas, NV

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

21-24 **Photomask Europa**
Dresden, Germany

July

9-10 **How to Successfully Manage New Product Introductions – SEMICON West**

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

12-14 **SEMICON West, North Hall – booth #5658**
San Francisco, CA

August

11-13 **SEMI FPD Expo China**
Kunshan, Jiangsu Province, China

16-19 **IEEE Conference on Nanotechnology**

September

13-15 **SEMICON Taiwan**
Taipei, Taiwan

27-29 **IEEE International Symposium on Semiconductor Manufacturing (ISSM)**

October

3-6 **International Trade Partners**
Hawaii, HI

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decisions. However, ESH impacts are also important drivers for the industry. Addressing ESH issues has resulted in major modifications to manufacturing equipment and processes because these issues were not considered in the decision making process. Modification of existing manufacturing equipment and processes increases manufacturing costs and cost of ownership. A sound decision making strategy that considers ESH issues during design has great potential for producing semiconductor manufacturing processes and equipment with long-term cost of ownership advantages.

SEMATECH has initiated a research project with Oregon State University and Wright Williams & Kelly to provide tools for considering ESH impacts on manufacturing process and equipment decisions. These tools may be used by process engineers, tool design engineers, and ESH professionals in evaluating process and equipment alternatives. The cost of ownership (COO) tool addresses the ESH cost impacts of semiconductor manufacturing. An activity-based cost accounting methodology and life cycle analysis techniques were used to guide the development of the ESH cost framework. The strategies for conducting the research were to:

1. Review ESH cost accounting literature
2. Develop a meaningful ESH cost framework
3. Pilot test the framework in the semiconductor industry

The findings of the research will be used to improve WWK's TWO COOL® software, provide application specific training for ESH cost analysis, and extend the SEMI COO Standard E35 to address ESH cost issues.

Literature Review

The review of literature assessed ESH cost factor identification, accounting, and estimation literature citations since 1985. In addition to journals, new unpublished research in both the public and private sectors was evaluated to the extent available. The review considered both practices and measures for ESH cost analysis. The ESH practices studies included citations that identified cost factors associated with ESH practices. The measures studies included citations that presented a system of accounting for ESH costs, estimating those costs, and determining profitability measures. The literature review led to the following conclusions:

1. Critical business and operational decisions are incomplete when ESH costs are not considered.
2. ESH costs must be accounted for and linked to the manufacturing process steps the drive the costs.
3. Conventional accounting practices are a critical barrier to proper identification of ESH cost drivers.
4. Conventional semiconductor capital budgeting and investment analysis techniques do not consider a sufficiently long time horizon to capture the return on investment in ESH investments.

ESH Cost Framework

Based on the conclusions formulated from the literature review, we constructed a framework for the accounting activities that drive ESH costs at the manufacturing process step level. ESH costs are allocated to the manufacturing process step based on the demand for ESH activities. This framework considered both activity based accounting (ABC) and life-cycle analysis (LCA). Cost driving activities were identified within this framework and defined based on ABC, LCA and COO literature. Following is a brief description of the LC phases and corresponding ESH cost drivers:

Phase I: Pre-Acquisition
The life cycle phase concerned with studying and ascertaining the relative risks and economic impacts that a chemical, material, tool, or process could have on the manufacturing process step, factory environment, or external environment.

- Assessing Relative Risk
- Assessing Economic Impact
- Formulating ESH Countermeasures Strategy

Phase II: Acquisition
The life cycle phase concerned with acquiring permits to generate emissions and procuring capital resources to control exposures to chemical, material, tool, and process hazards.

- Acquiring Permits
- Procuring ESH Resources
- Chemical, Material, Tool Facilitation
- ESH Management & Technical Support

Phase III: Use
The phase concerned with using the chemicals, material, tools and ESH capital resources in a manner that enhances manufacturing competitiveness.

- ESH Operations Support
- ESH Capital Operating Cost
- Environmental Processing Actions

Phase IV: Disposal
The phase where a chemical, material, or tool no longer adds value and exits the manufacturing process.

- ESH Management & Technical Support
- Disposal ESH Capital Operating Cost
- Environmental Processing Actions

Phase V: Post Disposal
The phase where a waste exits the factory location and control is transferred to another party.

- ESH Management & Technical Support

Incident costs are treated separately from ESH life cycle costs. By definition, incidents are unplanned. They adversely affect the manufacturing process step, the internal factory environment or the external environment. Incidents may occur during acquisitions, use, and disposal phases. Incident cost drivers include:

- Internal ESH Incident Costs
- External ESH Incident Costs
- Non-Compliance Fines & Facilitation

ESH cost factors may be categorized in many possible ways. This framework provides a useful tool for understanding the ESH cost drivers associated with the life cycle phases of a manufacturing process step.

Pilot Studies
Pilot studies are in progress at several semiconductor manufacturing sites of SEMATECH member companies. These pilot studies include lithography equipment, etching systems, planarization, ion implant, distribution and abatement systems. Life cycle ESH costs of the pilot studies are summarized in Table 1.

[Continued on Page 6]

Wright Williams & Kelly Names Cook Associates Sales Agent

Continues Steps in Global Expansion of Sales and Service

February 19, 2004 (Pleasanton, CA) –Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today the naming of Cook Associates Inc. as its sales agent covering the Eastern US. This appointment represents the continuation of WWK's strategic vision to provide increased sales and service support in close proximity to all of its customers, world-wide.

"Cook Associates was selected to support our growing installed base in the Atlantic States based on their long history of successfully meeting the needs of their clients," states David W. Jimenez, WWK's President. "They combine a comprehensive understanding of the region's high-tech climate and we look forward to working with them to support our existing installed base and expanding the application of our software products and services."

"We are pleased to begin representing WWK and its product line," says Ron Cook, Founder of Cook Associates. "We see a large demand for software tools and consulting services designed to help optimize manufacturing costs and productivity. WWK will help keep our clients at the forefront of cost competitive operations."

Cook Associates brings over forty years of selling experience in the semiconductor field to this agreement. Our philosophy is to represent firms that bring unique products and features to our customers that solve or improve manufacturing problems. Our goal is to provide value-added products to our customers.

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 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.

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Table 1
Life Cycle ESH Costs

Life Cycle Phase	Percent of Costs
Pre-Acquisition	3%
Acquisition	49
Use	29
Disposal	18
Post-Disposal	1

Confidentiality concerns restrict the disclosure of the detailed results of these pilot studies, but we have identified some general trends:

- The ESH cost accounting framework is a valid, useful model for understanding the activities that drive ESH costs in the manufacturing process.
- Management of ESH costs is improved when the activities the drive these costs are identified and related to manufacturing equipment and processes.
- Better analysis of ESH activities during pre-acquisition and acquisition can lower ESH operating costs during use and disposal phases.
- Recycling and reuse can eliminate post-disposal costs.
- Manufacturing activities may have ESH risks that do not become evident for many years. Thus investment analysis methods that focus on one to three year returns may not reflect the long-term ESH cost impacts.

Summary

The semiconductor industry is now realizing that ESH impacts of equipment, materials, and processes must be considered at the earliest possible stages of equipment and process development. ESH involvement in integrated process design is essential. This involvement can be by providing equipment and process designers with tools for evaluating ESH impacts on COO. If this involvement is successful, ESH considerations achieve the same stature as other decision drivers, such as cost, yield, and cycle time. Pilot studies confirm that early consideration of ESH impacts in evaluating alternatives allows development of processes and equipment with long-term cost advantages and improved return on the ESH investment.

Biographies

Daren L. Dance is Vice President for Wright Williams & Kelly, Inc. in Austin, Texas. Prior to joining WWK, he was a senior member of technical staff in Operational Modeling at SEMATECH. He is co-chair of the SEMI Metrics Cost of Ownership subcommittee.

Anthony T. Veltri, PhD, has over 15 years experience & research in modeling environmental safety and health (ESH) economics, strategy and organizational structure. He designed the Master of Science and Ph.D curriculum programs at Oregon State University. Dr. Veltri has consulted for semiconductor, aerospace, electric and utilities companies in ESH economic and emergency preparedness issues.

Wesley S. Lashbrook is a Project Technology Development Manager at SEMATECH. He is responsible for co-managing the Design for Environment, Safety and Health projects for SEMATECH. Wes has a Master of Environmental Health from Oregon State University and is a certified safety professional and Industrial Hygienist. He is a member of SSA, AIHA, and other professional organizations.

Lithography Cost of Ownership: Revisited

Daren L. Dance and David W. Jimenez
Wright Williams & Kelly, Inc.

Abstract
Understanding the Cost of Ownership (COO) and Return on Investment (ROI) of lithography is rapidly becoming one of the most complex analyses in a state-of-the-art semiconductor manufacturing environment. Understanding exposure tool COO is just the beginning. Additionally, one must understand the impacts of the other parts of the lithography cell on COO:

- Resist prime and deposition
- Resist thickness measurements
- Resist develop
- Critical Dimension and Overlay measurements
- Both pre- and post exposure baking and cooling
- Pattern inspection

In addition to the lithography cell components, other manufacturing operations have significant impact on lithography COO/ROI. Some of these include: planarization processes, mask design (binary or phase shift), and the characteristics of the film being patterned. We must also consider the maintenance schedules for all of the equipment used.

This paper will briefly review the COO/ROI issues for the components of today's lithography processes. We will then look at the impact of one of these issues, technology life, on COO and illustrate how production experience will impact the COO year-by-year as a process matures.

COO and ROI

Estimating cost of ownership is neither complex nor hard to do. With a few significant details, users can determine the life cycle cost of running a semiconductor process. The basic cost of ownership algorithm is described by:

$$C_W = \frac{C_F + C_V + C_Y}{L \times TPT \times Y_C \times U}$$

where:

C_W =	Cost per wafer
C_F =	Fixed cost
C_V =	Variable cost
C_Y =	Cost due to yield loss
L =	Life time of process
TPT =	Throughput
Y_C =	Composite Yield
U =	Utilization

ISSN 1094-9739

Fixed costs include purchase, installation, and facilities costs that are normally amortized over the life of the equipment. Variable costs such as material, labor, maintenance, utilities, and overhead expenses are incurred during equipment operation. Throughput is based on the time to meet a process requirement such as pattern imaging. Composite yield may include breakage, misprocessing, defects, and process control scrap losses. Utilization is the ratio of production time compared to total available time. Yield loss cost is a measure of the accumulated manufacturing cost of wafers lost through operational losses and probe yield issues. Yield models are used in COO calculations for estimating the relationship between contamination and yield loss or scrap. These models relate integrated circuit yield to circuit and process parameters such as device geometry, particle density, and defect clustering.

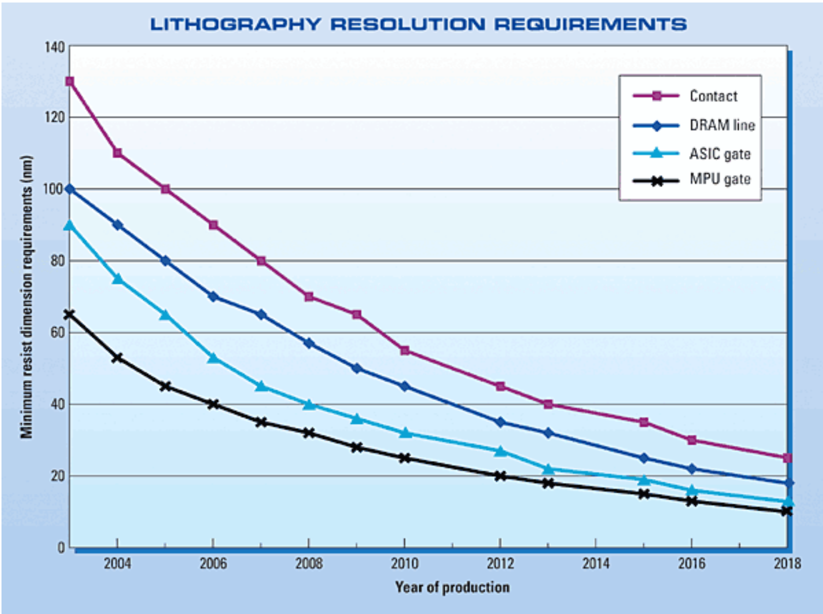
In some cases, simply knowing the cost contribution of alternative process steps to the total manufacturing cost is not enough. In comparative cases, a higher level metric is needed to assist in decision making. By leveraging the data provided by COO, it is possible to construct a simple, but effective ROI analysis.

$$ROI = \frac{\text{Benefit of Implementing Change}}{\text{Cost to Implement Change}}$$

The benefit could be the improvement in the COO value that resulted from a change in the process step under evaluation (new equipment, upgrades, material changes) multiplied by the number of wafers that will be run over a certain payback period (one to three years). The cost to implement the change might be the purchase price of a new tool, engineering man-power, or other items directly associated with implementing the benefit.

Leading Litho Candidates

Cost of Ownership and Return on Investment are identified by the 2003 ITRS as among the most difficult challenges facing lithography[1]. These challenges are typified by the resolution requirements for lithography illustrated in the following graph:



[1] International Technology Roadmap for Semiconductors: Lithography, 2003 Edition, p.3. See www.sematech.org.

Not evident in this graph is the fact that as the resolution requirements get smaller, the number of critical layers becomes larger, since the less-critical layers shrink as well. Thus, layers cross the moving boundary between non-critical and critical resolution requirements.

Some of the leading options mentioned in the 2003 ITRS for addressing these increasingly stringent lithography resolution requirements include:

- 193 nm optical – Has replaced 248nm for critical layers but still needs significant improvements in 193nm sensitive resists and CaF2 lens materials for future applications. Immersion lithography and other resolution enhancement methods have the potential to extend 193 nm to the 45 nm node line widths. COO issues include the costs of resolution enhanced masks and the impact of lens costs on exposure system cost.
- 157 nm optical – Still in early development and also requires advances in resist and CaF2 materials. Immersion lithography could enable 157 nm to image 32 nm node line widths. Resolution enhancement technologies will also play a significant role in the extended application of 157 nm optical lithography. Like 193 nm optical, cost of ownership issues include the costs of resolution enhanced masks and the impact of lens costs on exposure system cost. The impact of any pellicle method for 157nm on mask life also will impact COO.
- EUV – Significant development efforts have been focused on extreme ultra violet as a lithographic source. This technology is likely to be usable down to 16 nm node requirements, but the cost of the EUV exposure system may limit the potential cost effectiveness and COO of this solution.
- Electron projection lithography – EPL has been successfully implemented for some niche lithography requirements, especially where time-to-market is a driving consideration. However, concerns about throughput remain. Throughput could be improved with the development of more sensitive resists. Both throughput and resist cost will impact COO. The 2003 ITRS projects that EPL will be useable down to 22 nm node requirements.
- Imprint – Patterning using a 3-dimensional master image (somewhat like the stamping process for vinyl records) has also been successfully implement – but mostly for MEMS devices. The application of imprint patterning to nano-scale lithography is under active research. Imprint could have significant cost and throughput advantages if the resolution requirements can be met. COO analysis for imprint will need to include the costs of creating 3-D masters.
- Maskless lithography – According to the 2003 ITRS, "…many significant technological hurdles will need to be overcome for ML2 [Maskless Lithography] to be viable for cost-effective semiconductor manufacturing." Maskless lithography should be able to achieve 16 nm node line width requirements. Since masks are not needed, the COO may be lower but other COO issues have not yet been identified.

It is unclear which of these technologies, if any, can be extended beyond the 16 nm node lithography requirements.

<u>Litho COO Issues</u>
Estimating cost of ownership is neither complex nor hard to do. With a few significant details, users can determine the life cycle cost of running a semiconductor process. The basic cost of ownership algorithm is described by:

A review of next generation technologies suggests the following COO issues for lithography:

- Lens costs
- Costs of resolution enhance masks
- Resist costs
- Research and development costs

COO/ROI issues identified by the 2003 ITRS include:

- Achieving a constant or improving ratio of tool cost to throughput over time
- Cost effective masking methods
- Sufficient lifetimes for technologies
- Providing the resources for simultaneous development of multiple lithographic technologies

Some of these issues are summarized in the following quote from the 2003 ITRS, "Although many technology approaches exist, the industry is limited in its ability to fund the simultaneous development of the full infrastructure (exposure tool, resist, mask, and metrology) for multiple technologies. … Closely coordinated global interactions within industry and the universities are absolutely necessary to narrow the options for these future generations. [Meeting technology requirements] will drive major changes throughout the lithography infrastructure and will require significant resources for commercialization. These development costs must necessarily be recovered in the costs of exposure tools, masks, and materials."

Phil Ware, of Canon USA, points out another litho COO issue, "…industry indicators have been plotting paths that have made it almost impossible for tool suppliers to decide what technologies are real. In the absence of a clear indication of which method chipmakers might actually pick, tool venders are being forced to fund multiple development programs simultaneously, some of which are likely to be mutually exclusive."[2]

For example, millions have been spent on x-ray lithography over the past 25 years – still without production application in the semiconductor industry. Multiple litho development programs eventually impact litho COO through increased equipment prices – both as companies seek to amortize their R&D and as competitors are economically forced from the market, reducing competition that would otherwise help keep a lid on prices.

<u>Litho Learning Curves and COO</u>

Technology lifetime contributes significantly to both COO and ROI. The 2003 ITRS highlights technology lifetime as a difficult challenge for meeting both near-term and long-term requirements. The impact of technology lifetime is illustrated in the following example. We compare the COO by year for two cases:

1. An optical lithography system with a technology life of 3 years.
2. The same lithography system with a technology life of 6 years.

In both cases, the exposure system cost $5 million and the per-wafer costs including resist and masks are $8.005 per layer exposed.

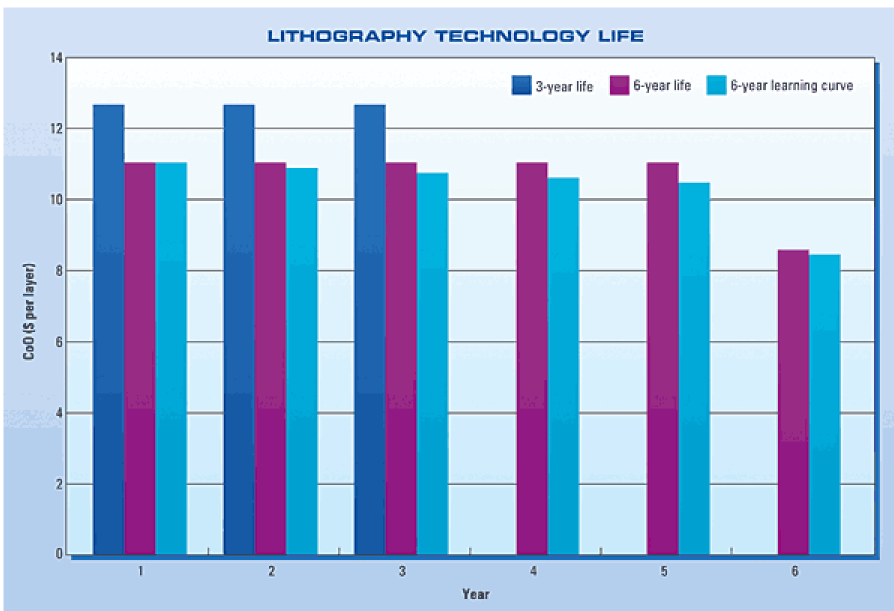
[2] Phil Ware, "The Perils of Chasing the Next Big Thing in Photolithography," in "Memories of 25 Years Gone by," edited by Alexander E. Braun, *Semiconductor International*, January 2004.

Table 1. CoO per Layer Exposed

Three-year life	$12.68
Six-year life	$10.63
Savings	$2.05

Thus, doubling the technology life allows many of the fixed costs to be amortized over a longer time frame, significantly lowering COO. For a 20,000 wafer per month fab, manufacturing a 20 layer process, the annual savings is $9,840,000.

Extending technology life also provides opportunities for productivity improvements gained through operating experience – the learning curve. Thus, we look at a case where, due to improvements in process and equipment operations, the number of production tests reduces by 10% each year and the throughput of the exposure system increases by 5% each year for a technology life of 6 years[3]. The following chart shows COO year by year for all three cases.



As is illustrated, in year 5, the experience gained through learning curve based process improvements adds another $2,688,000 per year in savings. Clearly, just addressing the technology lifetime issue identified in the 2003 ITRS can significantly improve the COO and ROI of next generation lithography. The reason that the advantage reduces in year 6 is that productivity improvements impact the allocation of fixed costs which have gone to zero for both examples by that time.

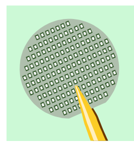
<u>Summary</u>

Understanding the Cost of Ownership (COO) and Return on Investment (ROI) of lithography is rapidly becoming one of the most complex analyses in a state-of-the-art semiconductor manufacturing environment. Just knowing the COO of the exposure tool is not sufficient. One must understand the cost impacts of the full infrastructure (exposure tool, resist, mask, and metrology) for multiple technologies to

[3] Note: Year 6 COO is lower because capital costs are depreciated over 5 years in both 6 year examples. Thus, Year 6 has no equipment costs – only operation, maintenance, and materials costs.

make these decisions. Multiple litho development programs eventually impact litho COO through increased equipment prices.

The ITRS has identified many COO and ROI issues. In this discussion, we have focused on the COO impacts of extending technology life. In addition to amortizing fixed costs over a longer time frame, extending technology life also provides opportunities for productivity improvements gained through operating experience. Clearly, addressing the technology lifetime issue identified in the 2003 ITRS can significantly improve the COO and ROI of next generation lithography.



Wright Williams & Kelly, Inc. Delivers Advanced Manufacturing Simulation Software to National Taipei University of Technology

April 13, 2004 (Pleasanton, CA) –Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today that it has shipped twenty-five seats of its latest version of Factory Explorer® capacity analysis and discrete-event simulation software to the National Taipei University of Technology. The software will be used as part of their advanced teaching and research in Industrial Engineering and Management.

Factory Explorer® is an integrated capacity, cost, and simulation analysis tool designed to help make smart business decisions. The Factory Explorer® capacity analysis engine quickly predicts system capacity and bottleneck resources; the cost analysis engine calculates product cost and factory gross margin; the fast discrete-event simulation engine estimates dynamic measures such as cycle time, work-in-process (WIP), and waiting times. These integrated modules eliminate the need to maintain separate factory models. The user interface brings powerful modeling tools to a familiar environment, automating and speeding the factory analysis process.

Common applications include:

- Capacity Planning
- Critical Path Supply Chain Analysis™
- Cycle Time Optimization
- Technology Transitions
- Factory Sizing
- Work-in-Process (WIP) Trending

Founded in 1912, National Taipei University of Technology has served Taiwan by promoting advanced and high-tech academic research and fostering the development of professionals with high-quality skills.

Wright Williams & Kelly Releases Factory Commander® v3.0

Wright Williams & Kelly, Inc. (WWK) has announced the latest release of its factory-level cost and resource evaluation software, Factory Commander® v3.0. Managers in the semiconductor, flat panel display, solar panel, disk drive, silicon, and other manufacturing and assembly industries use Factory Commander to quickly and accurately evaluate their strategic and tactical options.

The new features in this release provide even greater ability to model a wide variety of real-world situations. Some of the key features include an enhanced user interface, a custom report writer, and improved integration with other WWK applications.

Among the interface improvements is a navigation panel appearing on the left side on the application's main window. This panel allows access to the most commonly utilized screens. Items on the panel are arranged by function (general information, capacity & demand inputs, labor data, etc.) and are meant to compliment the drop down menus and button bar.

A custom report writer has been added to this release enabling users to create their own reports and save them for use with other models. Reports can be configured in one of four basic designs (row types): Tool Group based, Product based, Sector based or Process Step based. The columns for the reports are chosen from a predefined list of database fields available within the program. As many as six columns can be selected for each report. The number of columns and their order on the page are user-configurable attributes.

Some of the other functionality and interface enhancements include:

- Revised Modeling of Overhead Cost at Factory and Product Levels – Overhead modeling has been redesigned so that there is no longer a limit on the number of records that can be defined by the user. Also, cost inputs for overhead categories can now be assigned at the product level. This means that actual cost quantities can be input at the product level as opposed to allocation factors. This allows better control of how overhead costs are correlated to individual product types. Other aspects of this change include the input screen being divided into two pages: one for definition of the overhead categories, the other for entering the costing inputs at the factory-level, and the addition of category IDs and sort numbers.
- Ability to Save Multiple Sensitivity Analyses – Users now have the ability to save the settings and calculated results for more than one sensitivity analysis. This allows retrieval of analyses with different input parameters, input variable ranges, output selections (response variables), output dates, and/or output products. This feature allows the user to supply a name for the analysis which will appear on the reports and graphs specific to that sensitivity analysis.
- Multiple Labor Assignments at Equipment – The limit of three labor groups assigned to any individual tool group has been removed. Now as many different labor groups as desired can be assigned to equipment. This provides greater flexibility when modeling several different types of labor (operators, maintenance technicians, supervisors, process engineers, etc.), all of which are associated with the same type of equipment.
- "Unit Moves/Person/Week" Method Added for Labor Usage – A new option has been added as one of the methods for modeling labor at the equipment. This option allows labor to be modeled as a function of the number of production units (wafers, dies, etc.) passing through the tool or work station, thereby enabling headcount to be proportional to production volume.

Factory Commander® is the best choice for your factory's cost/resource evaluations needs. Let Factory Commander® help you reduce your manufacturing costs and show you the way to increased profitability.

ISSN 1094-9739

Wright Williams & Kelly Names veonis Technologies Sales Agent

Continues Steps in Global Expansion of Sales and Service

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"We are pleased to begin representing WWK and its product line. Their products and services fit nicely with our offerings in metrology," says Manfred Schwarz, President of veonis Technologies GmbH. "We see a large demand for software tools and consulting services designed to help optimize manufacturing costs and productivity. WWK will help keep our clients at the forefront of cost competitive operations."

Since 1972, veonis Technologies group has been a leading pan-European supplier of equipment, materials, software, and services to the semiconductor and related industries. veonis Technologies works in partnership with leading manufactures from the USA and Japan to bring cost effective solutions to the European market.

Drawing on nearly 30 years of experience in the semiconductor industry, the company provides world class service support tailored to specific customer requirements. The combination of product knowledge, application experience and service support makes veonis Technologies a premier single source supplier.