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Inside

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Estimating Pre-Horizon Short Interval Scheduling Simulation Errors

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Execution time is one of the largest obstacles to using simulation to evaluate potential rules for short interval scheduling of semiconductor fabrication. In fact, execution time has generally prevented this use of simulation to compare different applications of dispatching rules. This analysis will focus on one source of simulation errors that are compounded by longer execution times – pre-horizon simulation errors.

Let us assume that for the purposes of short-term scheduling, one would like to start at some Time 0 (t0) and simulate 10 different short-term scheduling scenarios. These scenarios can then be evaluated in terms of profit, cost, customer performance and other evaluation criteria to arrive at some preferred short-term schedule.

Ideally, we would start the simulation with the work-in-progress (WIP) inventory and resource status at t0. However, due to simulation execution times, we are constrained to using the WIP and resource status at some time point prior to t0 in order to complete the scenario analysis and implement the new short-term schedule by t0. For example, if each scenario requires one hour to simulate and analyze and there are 10 rule sets, then we base each simulation on the WIP and resource status at t-10, assuming serial processing of the data scenarios.

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Editorial Board

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Calendar of Events

December

1-3 **SEMICON Japan**
Tokyo, Japan

7-8 **AEC/APC Asia**
Hsinchu, Taiwan

January 2005

9-12 **Industry Strategic Symposium**
Half Moon Bay, CA

12-14 **Strategic Materials Conference**
Half Moon Bay, CA

February

2-4 **SEMICON Korea**
Seoul, South Korea

6-8 **Industry Strategic Symposium**
Berlin, Germany

TBD **WWK Road Show**
Tokyo, Japan

March

2-4 **SEMICON China**
Shanghai, China

April

12-14 **SEMICON Europa**
Munich, Germany

May

4-6 **SEMICON Singapore**
Singapore

9-11 **Strategic Business Conference**
Welches, OR

[Continued from Page 1]

Time t-10 allows sufficient pre-horizon time to accomplish the 10 simulations, assuming we do one at a time. The simulations can be done in parallel but each parallel simulation would require its own computer hardware and software license.

To properly evaluate the scenarios, each scenario should have identical starting conditions. Thus, the first portion of each simulation scenario is to simulate actual fab performance between t-10 and t0. The longer this pre-horizon period is, the greater the probability of pre-horizon simulation errors.

We can estimate the pre-horizon simulation errors from three sources:

- Equipment reliability issues
- Product yield
- Changes in operator availability

Reliability

A typical production fab, producing 20,000 wafers a month, requires about 260 pieces of equipment. If average equipment scheduled availability is 99.4% (i.e. down 1 hour a week), then there is a 0.5% probability that one or more pieces of equipment will be become unavailable during any hour of scheduled operation. Thus, there is about a 4.7% probability of failure at some time during the pre-horizon time between t-10 and t0.

Some of these equipment failures will have little impact on the WIP and resource status, but some failures could require wafer lots to be reworked or recleaned, thus, impacting more than one piece of equipment.

Yield

To produce 20,000 wafers a month requires an average total output of 30 wafers per hour per processing step. With 350 process steps and 99.99% yield, we can expect to lose about 1 wafer per hour due to random yield losses. This amounts to about 10 wafers during the pre-horizon time or an additional error of about 0.05%.

Operator Availability

The average operator works about 2,000 hours per year and has 2 to 3 days of unscheduled absence. This results in an operator availability of 99.85% to 99.95%. For this analysis we will assume 99.9% availability. Since a fab of this size will require at least 100 operators, we have a probability of an unscheduled change in operator availability of about 0.1%. If we assume a 12 hour shift, this probability is unlikely to change during the pre-horizon time.

These errors are summarized in Figure 1:

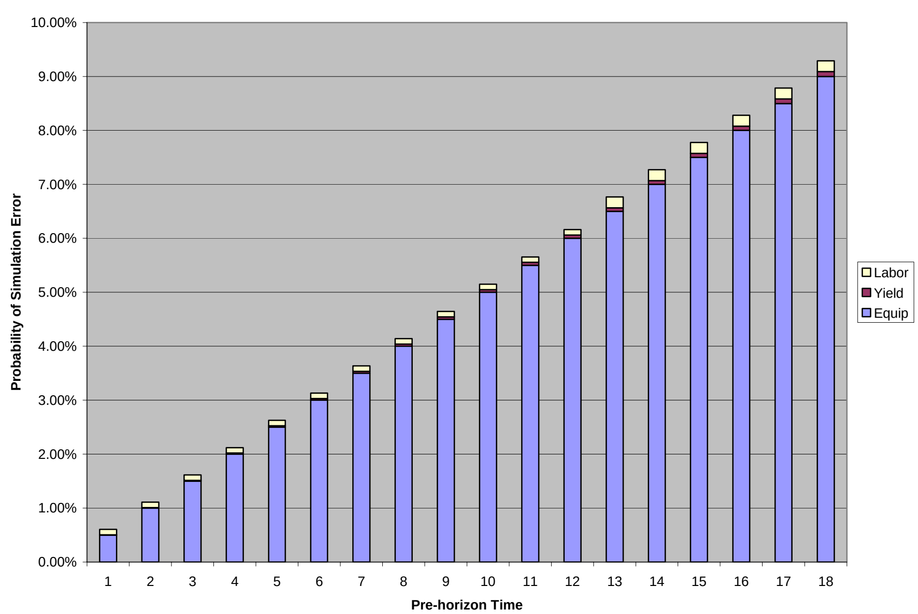

Figure 1: Pre-horizon Simulation Error Rates as a Function of Simulation Time

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Costs of Errors

A simulation-based short-interval schedule is used for positioning resources and for allocating production to equipment sets. If successful, the short-interval schedule will both lower manufacturing costs and increase product revenues. Errors in the short-interval schedule may increase manufacturing costs and reduce product revenues in the following ways:

- A manufacturing lot will be directed to the wrong processing equipment or arrive at the right processing equipment at the wrong time.
- Needed processing equipment will be unavailable due to scheduled maintenance being performed at the wrong time.
- Needed materials or other resources will not be available or will be in the wrong location.

Most manufacturers address these common errors using expediting, so the first cost of scheduling error is expediting cost. Expediting cost will be a function of how many lots need to be expedited. This can be estimated from Figure 1 using the following assumptions:

- 20,000 wafers shipped per month
- 25 wafers per lot
- 350 processing steps

These conditions require about 280,000 lot-moves per month under ideal conditions (no rework or dispatching errors) or about 70,000 lot-moves per week. The total error rate from Figure 1 attributed to equipment and yield issues is about 0.485% per hour. This means that for every hour of pre-horizon simulation time required, about 2.2 lots will be dispatched in error and will require expediting. If each error only requires about 10 minutes of an operator's time to find the erroneous lot and expedite it to the correct location, then expediting will require on average about 22 minutes of operator time per factory hour. Figure 2 illustrates how the equipment and yield caused simulation errors in Figure 1 translate into additional labor costs.

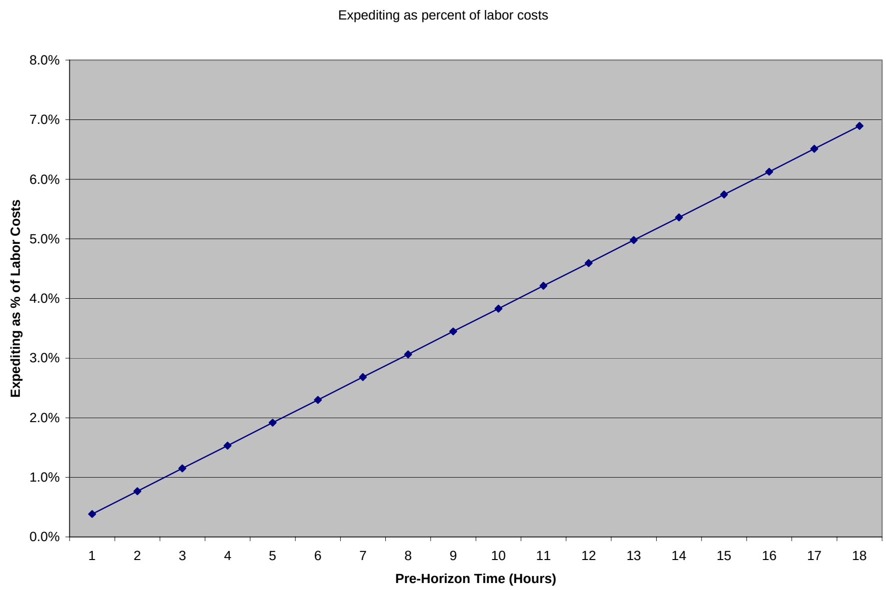


Figure 2: Expediting significantly increases labor costs

Expediting cost may exceed 4% of labor costs. With US labor rates expediting costs could exceed $67,000 per month. However, these errors also incur other costs to manufacturing:

- Decreased factory and equipment capacity
- Increased WIP with a corresponding increase in cycle times
- Reduced yield90% line yield

We can illustrate these impacts by looking at the impacts of expediting on equipment capacity, WIP, and cycle times. Many types of equipment in a fab operate at less than full utilization, but each fab has at least one type of equipment that is the capacity constraint to total fab output. Many times this bottleneck is lithography. Thus, 10 minutes of expediting time to get the right lot at the right place at the right time for lithography may effectively reduce factory capacity by 2.2%.[1] If a litho cell which includes a stepper, costs about $10 million, then expediting capacity constraints can add about $2.38 to the cost of each wafer produced or $47,600 per month.

Other types of equipment are operating at very near full capacity and can become bottlenecks if the WIP mix changes slightly. CMP equipment is an example of near bottleneck equipment in a well designed fab. Since product moves from CMP to litho and back to CMP several times, it is not unusual to find that the actual bottleneck moved from litho to CMP and back as lots move through the process. While CMP equipment costs much less than litho equipment, we can expect that CMP expediting capacity constraints at another $0.24 to the cost of each wafer produced or another $4,760 per month.

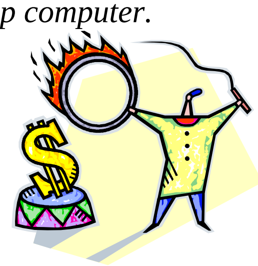
Expediting constraints and delays can also increase WIP by about 2% and extend cycle time by nearly a full day. These increase the value of WIP by about $220,000 per month on average.

The larger WIP and extended cycle times also increase the probability of yield loss. A 2% larger WIP at 99% fab yield means the probability that about 4 additional wafers will be scrapped per month. The value of these wafers if completed can range from about $4,000 to about $12,000 per month, depending on wafer size.

The following table summarizes typical expediting costs from extended pre-horizon short interval scheduling errors:

Source of Cost	Per Month
Expediting Labor	$67,000
Bottleneck Equipment Capacity Constraints	$52,000
Average Yield Loss	$ 8,000
Increase WIP due to expediting delays	$220,000
WIP carrying and stocking costs	$1,100
Total – Including Cost of Extra WIP	*$348,100*
Total – Excluding Cost of Extra WIP[2]	*$128,100*

Editor's Note: WWK's Factory Explorer® software is an ideal solution to the need for ultra-fast simulation. By combining an event graph paradigm, real-world process routings and interruption schedules, FX is able to achieve greater than 3.5 million lot moves per minute on a modest Windows XP based laptop computer.



[1] The capacity reduction due to expediting may actually be larger for AMHS equipped fabs as the time to return the incorrect lot to a stocker, locate and move the correct lot from the stocker to litho may be greater than 10 minutes. We have not considered the capacity impacts of expediting on AMHS capacity.

[2] Since there may be circumstances where management has already decided to operate at a higher WIP level, we include totals with and without the cost of the extra WIP. Carrying and stocking costs are included in both totals.

WWK Begins Shipping Metrology Analysis Module for TWO COOL® Cost of Ownership Software

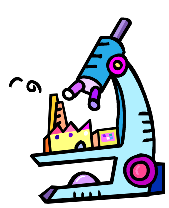
October 14, 2004 (Pleasanton, CA) –Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today it has begun shipping the next generation of its Cost of Ownership (COO) and Overall Equipment Efficiency (OEE) software, TWO COOL® v3.1. This latest version includes the capability to analyze the cost impacts of stand-alone and in-situ metrology & inspection and is being provided at no charge to existing software maintenance clients.

TWO COOL® is the de facto standard for COO and OEE analysis software used by industry and academia. Originally developed at the request of SEMATECH, TWO COOL® is used in the semiconductor and other industries to manage procurement and optimization of multi-billion dollar capital asset portfolios.

TWO COOL® version 3.1 incorporates not only the traditional metrics for process equipment but now includes critical features to measure the performance of metrology systems and sampling plans. Version 3.1 provides the ability to measure the cost impact of incorrect metrology/inspection results (alpha and beta errors). The inclusion of sampling plans allows metrology costs to be more accurately assigned to the total production being supported by the metrology tools. "Metrology COO analysis allows our customers to better understand the costs and benefits of measurement and control when implementing leading edge technologies," said Daren Dance, WWK's Vice President of Technology.

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.



Top 10 Modeling and Simulation Mistakes

Compiled by the Staff of WWK

We all like to think we are perfect, but we have made mistakes and we know our customers have as well. We have compiled this list so that we can learn from modeling and simulation mistakes. We hope you learn something as well.

1. Mismanaging model development - need to focus in getting answers to management questions. We have seen two versions of model development mismanagement: A) Attempting to build the super-model to answer all possible questions, and B) Attempting to model every detail and nuance of an operation, and in the meantime, not producing any meaningful results to management or the original requester. Both of these practices violate the KISS[3] principle - many dollars are wasted on implementing, failing to implement, and supporting models that are too complex for the problem at hand – directly contributing to project failure.

2. Using paper specifications instead of actual performance data or making assumptions about performance data from competing tools. A variation of this is comparing the expected performance of a new generation of equipment with the historical performance of current equipment. The data are the foundation of the model. While we know that all of the needed data may not be available, use sensitivity analysis to explore the impacts of unknown performance data on the simulation or model.

3. Under-estimating efforts for data collection and data maintenance. We reiterate – the data are the foundation of the model. We often find that data collection takes twice as long as initially estimated, but that extra effort reaps rewards in improved model accuracy and shorter validation and testing efforts. Also, don't fall into the trap that if the data was good last year it is still good. Data, like lettuce, spoils with time and needs to be revalidated.

4. Relying on a single modeling/simulation metric. The manufacturing operations we model and simulate are too complex to be defined by a single metric. In addition to cost, we also look at utilization, capacity, and yield metrics. For simulations, the factory performance curve[4] also provides a broad view under different operating conditions.

5. Releasing preliminary results indiscriminately before they are verified. Preliminary results are an important part of validation, but they should be selectively used as part of the validation process. A simulation analyst was recently embarrassed in front of a customer by showing a preliminary result that inadvertently mixed inputs of different types. This was corrected as the data were verified.

6. Using modeling results to beat up suppliers. Next time some won't cooperate. You need accurate supplier data to make best decisions. The best source of that data is your supplier. Supplier data, like all other data needs to be verified, but don't allow differences in data to close the communication channel.

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[3] KISS – Keep It Simple, Stupid

[4] Cycle time vs. Factory Loading vs. Product Cost

7. Underestimating "management's" ability to understand simulation results, leading to the over use of animation. Animation may just be the "demo"' not the real model. While animation is useful to show overall flows – modeling and simulation statistics are necessary to really understand the differences between two different operation scenarios. See mistake #4 for additional details.

8. A Graphical Users Interface may not necessarily reflect the true effort of building a model. The GUI may be fun to use at the beginning but tedious at the end or if large amounts of data must be entered. Having several different methods for data entry, including imports from spreadsheets, can accelerate complex model development.

9. Mishandling change management - Are you using the right version of the model for simulation? When several modelers are working together on a project, who has the latest version? Some initial effort on methods of identifying changes to a model, changes to the data and model versions will simplify validation efforts leading to quicker, more accurate results.

10. Letting model developers do their own quality assurance. To quote a recent article, "allowing engineers to perform their own QA is akin to allowing defendants to be the judges and juries for their own trials.[5]" Independent review is an important part of model and data validation. For example, a recent internal WWK model was prepared with one set of inputs in *minutes* and another set of inputs in *seconds*. Unit consistency is the first step in modeling

WWK Begins Development of Factory Explorer® version 2.9

Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today that it has begun development of its next version of Factory Explorer® capacity analysis and discrete-event simulation software. Delivery is expected in the first quarter of 2005.

Some of the new features include:

The ability to seize tools, such as test boards, where multiple tools are required per lot and hold them until the operation is completed.

Provide for more descriptive naming of split lots.

Add more details to events on Scheduling Worksheet.

Add "moves/unit time" simulation results to the Tool Group Report.

Add tools dedication feature where a lot must return to the exact same tool on subsequent process steps.

Add a time restriction when a lot must be processed by the next step within a certain time window.

[5] Chad Dickerson, "The Top 20 IT Mistakes," Infoworld, 22 Nov. 2004, p. 38. Also see www.infoworld.com.

SEMI E35 Gets a Makeover
Reflected in TWO COOL® 3.1

David L. Bouldin, Texas Instruments and Daren Dance, WWK
Co-Leaders, SEMI Metrics Committee Equipment COO Task Force

Many of us go on a diet to prepare for the holidays. So did SEMI E35 – *Guide to Calculate Cost of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment*. In its latest revision, passed by SEMI's Metrics Committee on 27 October 2004 for official publication in March 2005, E35 slimmed down from 34 pages to 16 pages and added a few new features.

The *Guide to Calculate Cost of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment* has been reviewed and updated as part of the continuing cycle of SEMI Standards reviews. The purpose of this update was to implement the following revisions:

- Bring E35 into compliance with current SEMI Standards editorial guidelines and practices. Thus, the COO for Gas Delivery Systems Appendix was removed and simultaneously balloted to become an independent standard SEMI E140 – *Guide to Calculate Cost of Ownership (COO) Metrics for Gas Delivery Systems*.
- Update E35 to reflect changes in related SEMI Standards such as SEMI E10 – *Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability*, SEMI E81 – *Provisional Specification for CIM Framework Domain Architecture*, and SEMI E89 – *Guide for Measurement System Capability Analysis*.
- Add an appendix for estimating Alpha and Beta error in COO estimates related to metrology.
- Simplify the application of this document to COO calculations by eliminating duplicated information and by generalizing the document to encompass all of semiconductor manufacturing – not just integrated circuit manufacturing at the wafer level.

E35 has been in widespread use since its original adoption in 1995. No substantial changes have been made in the fundamental equations that were described in the 1995 document, but the document simplification and editorial changes were needed to allow continued usefulness of E35 for calculating COO.

Following are some of the improvements in this new version of E35.

- **Expand applications** – In 1995, the wafer fab was the major focus for COO. Since then, users have applied COO to many areas other than wafer fabrication. Thus, most references to wafers have been eliminated from the latest version – preferring the more generic term *unit*. (See E35 Section 5.2.51.)
- **Consolidate definitions** – In compliance with current SEMI editorial guidelines, definitions have been consolidated into the terminology section of the document. The previous version only defined 40 terms, while the latest version defines 55 terms. Definitions of some of the 15 additional terms were scattered throughout the 34 pages of the previous document.
- **Refer to new related standards** – The prior version only referenced two related documents and one of those documents has been withdrawn. E35 now references 4 documents, including a related ISO[6] document – *International Vocabulary of Basic and General Terms in Metrology*.
- **Eliminate duplication** – Many terms and variables in COO were defined and described in two or more places in the prior version. While the original intent was to improve usability of the document, in practice the opposite occurred. In fact, during the revision, the committee found

[6] International Organization for Standardization: ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland, Telephone: 41.22.749.01.11; Fax: 41.22.733.34.30, Web site: www.iso.ch.

that the duplicate descriptions of some variables were different. A variable was defined one way in one table and another way in a subsequent table. All variations in definitions have been standardized.

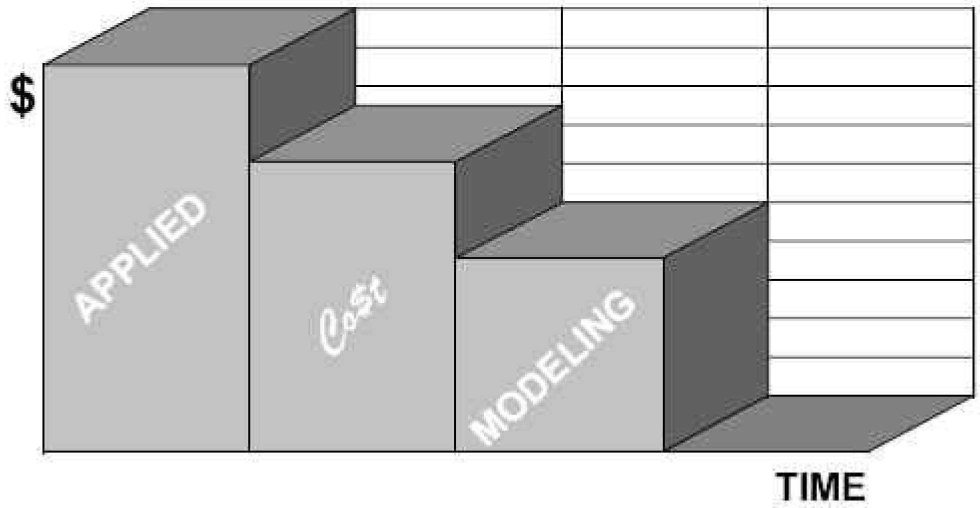
- **Add metrology** – While the prior version included alpha and beta error for metrology applications, the latest version provides an appendix with a method for determining alpha and beta errors. This greatly enhances the application of COO for test and metrology. Now that there is a standard method for estimating these errors, WWK has added alpha and beta errors to TWO COOL Version 3.1.
- **Create a separate standard for COO for gas delivery systems** – *Guide to Calculate Cost of Ownership (COO) Metrics for Gas Delivery Systems* was originally planned as a separate standard. However, since COO was mentioned, it was combined with E35 as an appendix. Some important variables have different definitions in gas delivery system analysis. The scopes of the two parts of the document were also different. These differences led to confusion, which we hope to eliminate through issuing a separate document. Now, SEMI Standards users can purchase just the document they need, whether for equipment (E35) or for gas delivery systems (E140).
- **Eliminate constraint versions –** The 1995 version tried to establish a standard basis for COO analyses that eliminated certain variables. In practice, we found that COO models should be developed to address specific management questions. Since the motivating questions vary, so do the information required in the answering COO models. We have now (see E35 Section 6.2) transferred the burden of defining constraints to the users involved in a specific analysis, "Constraints should be predefined by all stakeholders in a specific equipment COO model, prior to estimating COO, to minimize biasing of the COO estimate." This change eliminated another source of duplication and potential error.

What has not changed – The basic equations defining COO have not changed. Neither has the related information for "Example Values." These are unchanged to provide continuity with prior COO estimates. This means that the user of COO can continue to use existing models in their analysis. However, the new features and simplifications expand the application of COO and clarify the usage of many terms.

For further information on SEMI Standards, see www.semi.org. For further information on TWO COOL® cost of ownership software, see www.wwk.com.

Late Breaking News

- WWK has signed an agreement to reopen sales and service in Japan. This partnership with Selastar Corporation will bring one of Japan's most respected organizations into the WWK family.
- Keep your eyes open for WWK's web site face lift. The changes will not only enhance the aesthetics but also make it much easier to search the site for critical information.



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