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OPERATIONAL MODELING & SIMULATION IN SEMICONDUCTOR MANUFACTURING

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ABSTRACT

We present a panel session on the role of simulation in improving semiconductor fab operations. The participants include three principal investigators (PIs) from the recently awarded three-year, $1.2 million contracts sponsored jointly by the National Science Foundation (NSF) and the Semiconductor Research Corporation (SRC) on Operational Methods in Semiconductor Manufacturing; the Factory Sciences Program Director from SRC; and industry representatives from the semiconductor manufacturers and from discrete-event simulation vendors. Included here in these proceedings are initial position statements from the various participants, which formed the basis for the panel discussions. For the industry participants, the statements may include, but were not limited to, specific important problems related to the role of simulation in operations in their respective companies, noting any significant technical, managerial, market, or other barriers. The position statements of the academic PIs describe the role that simulation is expected to play in their ongoing research in semiconductor manufacturing and/or their views on the key to successful application of simulation in the industry.

1 INDUSTRY POSITION STATEMENTS

Disclaimers: The views expressed in these position statements are those of the individual panel participants, and do not necessarily represent the views of the employee's company or other individuals employed by the company.

Steven Brown, Siemens AG

I believe Siemens Semiconductor Division is today just in the fledgling stages of using simulation to improve factory performance. The emphasis at Siemens is to integrate simulation activities into the decision-making process of the factory managers.

For current factories the greatest potential lies in sensitivity analysis of operating policies, with a focus on meeting new production goals while avoiding equipment purchases. For Siemens, there is particular benefit to come from a better understanding of the impact of product mix changes; staffing levels (particularly in the back-end); and people utilization.

For future factories simulation should be used effectively with specialized software to evaluate and analyze solutions for equipment layout, material flow, and automated material handling systems to minimize tools, space, costs, and cycle time. Simulation should also be used in conjunction with overall equipment effectiveness (OEE) efforts to evaluate the impact of changes in equipment parameters. The goal here is to produce a priority list of realistic equipment improvement programs for manufacturers of advanced-technology tools (i.e., 300mm).

For all factories, simulation can be linked directly with other common programs:

- Scheduling systems can be implemented to improve on-time delivery and can be integrated with system-level logistics programs to improve capacity allocation/analysis for business plans.
- Simulation can be used to set the targets/goals of factory-level OEE programs and cycle-time reduction programs.

Frank Chance, C2MS Productivity Solutions

“Credibility is not a gift – it has to be earned. It is built up one step at a time and supported by facts, and by consistency. Even more, credibility is never owned; it is rented, because it can be taken away at any time – Pedro Aspe, 1993."

I think that simulation suffers from a credibility gap in semiconductor manufacturing. This is not to say that all simulation projects have been failures – there have been notable successes. But there have been many more cases where results did not meet expectations. As a vendor of simulation and factory analysis software, this is obviously an issue that concerns me. To address it, I believe we need to examine our expectations for simulation users. First, we expect users to be proficient with multiple pieces of computer software – certainly our own, and then probably Microsoft Word, Excel, and PowerPoint, if the user is to ever do in-depth analysis and presentation of simulation results. Second, we expect users to have sufficient project management skills to oversee an implementation of our software. Third, we expect users to be to politically adept, as they must often interact and negotiate with three or more functional business units for most implementations. And let’s not forget that we also expect users to understand simulation, statistics, and even a little probability! Is it any wonder that simulation users face an uphill battle to meet the expectations placed upon them, and in turn, that simulation projects often fail to meet expectations?

We could place blame on the university for not providing graduates with this well-rounded skill set. We could place blame on the simulation vendors for products that require too broad an array of user skills. We could even place blame on the client for expecting too much from simulation, and not providing enough skilled users. But shouldn’t we in the simulation community view these expectations as a challenge to be met, rather than as a bar to be lowered? Given these constraints, I would say a good simulation software product is a necessary, but not sufficient, condition for success. My approach is to treat the first several projects with a new client as apprenticeships. An experienced analyst from our company serves as project manager, and the project team includes members from our company and from the client company. These initial projects concentrate on delivering measurable, concrete results – to build credibility – and on preparing the client to run his/her own projects. For I believe that the best way to train a simulation analyst is to have them work for and emulate a simulation analyst who is successful. It’s slower, surely, and takes more resources, but is there ever a shortcut to credibility?

Sean Cunningham, Intel Corporation

Fast, cheap, good: pick two. This is the dilemma of discrete-event simulation modeling as applied in operational settings.

Fast, cheap models damage the credibility of our discipline. Implicit assumptions are not well understood. Verification and validation are left undone in the rush to results. Customers are disappointed when the results of the model do not match their operational realities.

Fast, good models require inordinate computing, customer, and developer resources. Exquisite coordination of operations staff, software developers, and management is required. Several individuals must know their roles immediately and execute on them.

Cheap, good models have timelines that exceed the time horizon of the problem itself. The typical factory trains one or two simulation developers in the software technology; their progress is gated by their need to train their peers in the assumptions, needs, and interpretations of their models. The single developer can quickly and easily become overwhelmed by the detail of the problem, and can become frustrated when progress is slow.

How to achieve fast, cheap, and good? First, we must realize that not everyone will be a simulation modeling expert. No quantity of additional features added to standard software packages will save inexperienced modelers; experienced modelers will almost always choose to write their own features. It is the duty of management to recognize and reward those individuals who excel in modeling, and to weed out those who do not.

Second, we must insist upon model, software code, and developer re-use. A general model that approximates several scenarios is better than several specific models. Object-oriented software tools are a step in the right direction. Intact development teams that persist through several modeling projects are becoming a necessity.

Finally, we must pick the right problems. Simulation modelers can tend to live out Maslow’s comment that, to those skilled with a hammer, all problems are nails. Valuable simulation resources must be spent on projects for which simulation is the best feasible solution methodology. Where appropriate, queueing theory, linear programming, and analytic optimization should be preferred to simulation modeling. In the rapid turn-around time environment typical of operational settings, modelers should be rewarded not only for the simulation projects they perform, but perhaps also for those they prevent.

Courtland Hilton, Intel Corporation

We simulate complex semiconductor factories simply because they are too large, too complex, and too costly to optimize and refine any easier way. Increased complexity in our products as well as in our manufacturing systems is the natural result of the market and business pressures of today coupled with the hard limits of physics. Our goal is to often have our simulation studies return 100x their investment (although I will do them for a 10x return).

We need help to accomplish this. We need tools that allow complex customization but at the same time are robust, bug free, and are supported with detailed and complete documentation and training. We need languages and environments that allow us to increase code reuse by easily exchanging modules, rules, and functions between models. We need languages that abstract us above the code level and let us "speak" in terms of strategies and plans. We would benefit from well-developed industry specific frameworks so that third-party companies and equipment vendors could develop plug and play modules. This framework would also assist many of our simulation engineers who do not have the software engineering background necessary to develop coherent and global frameworks. Data quality and availability is a tremendous problem. Much of that we own internally. But we would benefit from better designed interfaces and database links to facilitate model data loading and complex data management.

Validation is a key issue. Models must be provably correct if they are to be used with confidence in high cost decisions. The rub, of course, is how to validate the model and the simulation, especially when one may be modeling a factory of the future that does not yet exist. Such a validation is often a hybrid of comparisons to physics models, to portions of existing manufacturing processes, to specialized experiments, and to intuition. Tools and practices to facilitate these for industry specific models would be of value.

Simulation is not always the right tool to use. Even when it is, it is not always clear what level of abstraction should be used within the model. Carefully developed guidelines for generic industry problems would be most useful in reducing the time to solution. We also need vendor support for this. For example, people are generally handled abominably in most packages which treat people as little more than a jig or fixture. We need to represent people who think, who preempt work, who set dynamic goals and who behave, in general, like real people do.

Simulation is a wonderful tool and besides, is a lot of fun. As we work to develop these further capabilities we will expand the user base, shorten the time between new question and new model, and increase the effectiveness of our operations. May that be our lot!

Mani Janakiram, Motorola

Many operational decisions are made in the industry purely based on prior knowledge, experience and intuition. Operational modeling and simulation is being used in all industries to perform factory analysis. The semiconductor industry, in particular, the wafer fab operations, pose several challenges to modeling and simulation, due to varied complexities which include reentrant flows, use of cluster tools in fab operations, etc. Given the high cost of building a fab, high equipment cost, dynamic market changes and technology innovations, it is imperative that Motorola should position itself to be a market leader in all their product portfolios. However, in order to understand the true stochastic implications of an operation, it is necessary to build a meaningful model and perform simulations to study the operation in question. Several models have been build and many simulation studies have been performed to improve fab operations and to achieve the goal of keeping the company profitable and providing world class customer service.

At Motorola SPS, factory simulation is performed for capacity planning, scheduling, bottleneck identification, impact of new product/process flow, additional equipment justification, layout analysis, functional equipment modeling, cost modeling, yield modeling, lot size sensitivity analysis, operator modeling, factory ramp-up modeling, etc. The performance measures normally analyzed are: cycle time, throughput, WIP, equipment usage and cost. Like every other industry, Motorola uses simulation for making rational decisions and stands to gain from these virtual factory operations with the help of simulation. Several simulation packages are used at Motorola but the simulation packages by Tyecin Systems (now part of Manugistics) and AutoSimulations are extensively used in addition to Cost Resource Model (from SEMATECH) and others.

It is critical that the simulation models provide meaningful data which depends primarily on understanding fab operations, input data accuracy, proper model building and output data validation. It is also essential that the model be kept up-to-date in order to reflect the current factory scenario. This can be accomplished by having a good, user friendly interface between the simulation package and the manufacturing execution system.

Rick Stafford, AutoSimulations

Traditionally simulation in semiconductor manufacturing has been used for high level capacity planning. Its use is now rapidly growing in other fields such as scheduling, detailed equipment modeling, and manufacturing control system emulation. This growth can be attributed to the ability of simulation software tools to accurately model semiconductor manufacturing operations. It is not unheard of today, to have the ability to create a model of an automated system with upwards to 98% accurate representation. Much of the focus from software vendors has been exactly this, the ability to accurately depict manufacturing operations. What has suffered greatly in industry is the ability to analyze these systems to provide optimum or near optimum solutions to the problems being addressed by simulation users.

Software vendors are always positioning themselves between how good the software is in terms of features, performance, accuracy and cost. What is often forgotten is what it takes the end-users to solve the issues dealt with in manufacturing using these state-of-the-art software tools. There does seem a need for some collaborative effort in the context of simulation analysis by employing the combine skills of industry, academia and the end-user.

Randy Hughes, Tyecin Systems

To be provided at the conference.

2 ACADEMIA POSITION STATEMENTS

John Fowler, Arizona State University

I see two major things that limit the proliferation of the effective use of operational modeling and simulation in the semiconductor industry. These are: 1) the amount of time and effort that go into identifying, specifying, collecting, synthesizing, and maintaining the data used in modeling efforts; and 2) the lack of perceived value of these efforts by semiconductor management. Some thoughts on both of these are given below.

Typically, the developers of simulation models spend a very large percentage of their time gathering data and preparing it for use in their models. The first step is to actually determine what data is needed to model the situation being investigated. Sometimes we are lucky enough that the needed data is available in an electronic form and sometimes it only exists on paper or must be collected from scratch. When it is available electronically, a computer program generally must be written to convert the data into a form that can be read by the software package being used. All of the suppliers of modeling packages on the market today have done a lot of work to facilitate these types of efforts and they are to be commended. The next step in this process is to develop standards that can be used to reduce the amount of time and effort necessary to extract the required data from Manufacturing Execution Systems and from other modeling packages. SEMI Draft Doc. 2895 Guidelines for Operational Modeling Data Standards (MDS) is a first attempt for such a standard. I should point out that I do not think that all semiconductor manufacturing models should have the same level of abstraction because I firmly believe that the best model is the simplest model that answers the question being asked. However, MDS should provide for reduced effort required to get data that is commonly used. Like other standards, MDS will evolve over time to encompass several different levels of abstraction.

Operational modeling and simulation efforts in the semiconductor industry have come a long way in the decade that I have been involved in the industry, but still face an uphill battle for respectability. While those of us involved with the development and use of these models know their value, in many cases, the powers that be in the industry remain unconvinced. Therefore, we spend a lot of time and energy in trying to “justify our existence." It seems to me that this is primarily a public relations problem. There has been lots of excellent efforts, but we have not done a very good job of publicizing our successes. Justifying our existence has led us to often “oversell" our work and not manage expectations properly.

Michael Fu, University of Maryland

One thrust of our research aims to bridge the substantial gap that currently exists between modeling at the process level and operations at the fab level. We are developing an approach that integrates operational level models and process level models for the purpose of qualitatively and quantitatively assessing how process level improvements and changes benefit fab-level production objectives. Using a tungsten plug subfactory, we are incorporating process response surface models into a discrete-event simulation model, in order to provide substantially more insight and capability than current practice, which uses only fixed process parameters that are set based on optimization at the process level, performed in isolation from operational impact. These aggregate process models are being generated from detailed physically-based dynamic simulations of process and equipment behavior or from empirical process data. The resulting ability to integrate models of differing character (e.g., continuous parameter and discrete-event) will provide new support for decision making by both equipment and operations managers.

Just as the principles of concurrent engineering brought together design and manufacturing engineers, the proposed research integrating fab-level simulation with process models will serve to bring together engineers from the process level and the operational level to enhance fab-level operational efficiency. Successful implementation of the proposed research will lead to insights into the sensitivity of operational decisions to underlying process parameters. These insights can then be used by operational and factory integration personnel to support discussions of suggested changes in parameter settings at the process level.

Lee Schruben, Cornell University

All simulation studies are successful!

Let me assure any C programmers in the audience that I did not unintentionally transpose the word “successful” with the ! (NOT) operator. However, I am far from certain that I will be able to convince even people here at the Winter Simulation Conference that the above statement is true; but, let me try. First, we must be willing to view simulation not merely as a computer program, but as a way of thinking about systems. At a high enough level, simulation is indeed a philosophy. I mean this in a very real, practical sense: simulation offers us a framework for structured thinking. I believe that people with experience in simulation think differently than other people; I would argue that they think better. People experienced with simulation modeling better understand dynamic relationships between events. They recognize potential performance tradeoffs, resource constraints, and process interactions. Perhaps most importantly, from a constant use of statistics, they can concentrate on the likely rather than be distracted by the unusual.

On a practical level, simulation is conventionally viewed as a tool for answering questions. It is a radical, yet productive, departure in thinking to regard simulation as a technique for asking questions. For example, simulation might be used to answer the question: What is the capacity of our system? - On the other hand, simulation might be used to ask the question: Is our demand likely to exceed 1050 units/day? The question asked of the simulation is vague with no action implied. The question generated by the simulation is precise with an immediacy that comes from knowing (from our simulation study) that when demand exceeds 1050 units/day our system will break.

I sometimes feel that engineers attach too much importance to answering questions and not enough importance to asking them. I am fond of asking freshmen in my Introduction to Engineering seminar the following question: What do they call a person in a company who answers technical questions? Answer: An engineer. I then ask them: what do they call people who ask technical questions? Answer: The Boss.

A well formulated question is much more valuable than dozens of answers to vague “what if?’s".

To try and complete my argument that all simulation studies are successful, I need to define what I mean by “success". I do not regard success as a simple Boolean “Yes" or “No"; success comes in different shades, flavors, and colors. Obviously, I can’t require that all the recommendations from a successful simulation study be implemented. For success, I require only that the study results be observed and, for a higher degree of success, discussed? To even contemplate doing a simulation, one needs to think systematically about a system; having the opportunity and motive to do so is in itself success. A simulation program, even if it is not literally “correct" is likely to highlight the importance of such system fundamentals as resource bottlenecks and, more importantly, that a system bottleneck is dynamic; I call that success.

If we take the view that simulation is more than a computer program, we realize that the act of creating, or even thinking about creating, a simulation involves consideration of system performance measures and how system elements interact to influence these measures. Identifying, communicating, and attempting to understand system tradeoffs makes us smarter; I call that success. The process of simulation forces us to distinguish between laws (rules not under our control) and policies (rules we get to make); I call that success. The process of simulation allows us to think not only of the constraints that limit our options, but on what is possible; I call that success.

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FRANK CHANCE is a specialist in productivity measurement and improvement for C2MS Productivity Solutions. Prior to C2MS, he founded Chance Industrial Solutions, a provider of software and consulting services for the semiconductor industry. He is the author of Factory Explorer(R), an integrated capacity, cost, and simulation analysis tool. He has consulted on factory improvement projects for clients such as Siemens AG, Digital Equipment Corporation, and Seagate Technologies. He holds a B.A. (1987) degree in mathematics and history from Washington University in St. Louis, and M.S. (1991) and Ph.D. (1993) degrees in Operations Research from Cornell University. He has taught at Cornell and at the University of California, Berkeley.

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