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APPLICATION OF SIMULATION AND THE BOEHM SPIRAL MODEL TO 300-MM LOGISTICS SYSTEM RISK REDUCTION

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ABSTRACT

Building on the lessons learned from the 150-mm-to 200-mm transition in semiconductor manufacturing, much work has gone into the planning and development of 300-mm fabs. Examples of this include the work produced by SEMI, International SEMATECH's I300I and Japan's J300 programs. This work includes various standards and guidelines regarding the architecture and interfaces of loadports, equipment and software components.

However, despite these efforts, there are a number of significant 300-mm risks that remain. Some of these risks involve specific fab operational methodologies, which may vary depending upon the type of fab involved. Additionally, there are many other risks associated with the development and implementation of a robust 300-mm logistics system.

The purpose of this paper is to:

- Define some of the key risks associated with the development and implementation of a fully integrated 300-mm logistics system.
- Show how simulation can be used in conjunction with a risk management approach, i.e. Boehm spiral model, to play a key role in the mitigation of those risks.

1 INTRODUCTION

In 1997, the semiconductor industry responded with several key international cooperation programs as a number of companies began planning 300mm fabs. In 1998, many of these new fab plans were put on hold. Not only was the 300mm equipment not viewed as production ready, but end users were concerned about the level of risk associated with the integration of a number of legacy automated material handling, manufacturing execution, and material control software systems that would be needed to manage the fab's logistics (integrated production and material movement).

The primary objective of this paper is to clearly detail how discrete-event simulation can play a key role in ensuring the successful development and implementation of 300mm logistics systems. This will be accomplished by pointing out some of the current risks and challenges associated with 300mm logistic system development. Then a risk reduction approach based on the Boehm spiral (1988) model will be described. Finally, the way in which simulation becomes instrumental in reducing 300mm logistics development risks using this approach will be illustrated.

2 300-mm LOGISTICS SYSTEM RISKS

There are a number of risks that must be fully comprehended and addressed before a logistics system can be successfully implemented within a fab.

2.1 Software Risks

One of these risks involves developing a fully integrated material logistics system where the manufacturing execution system (MES), material control system (MCS), and the automated material handling system (AMHS) and other production system software work in a closely integrated arrangement. Previous factory control systems were designed around a Human-Centric philosophy, where they were interfaced with the automation systems that followed. The assumption was that operators would make decisions concerning scheduling, changes to schedules and material movement. A Schroeder (1997) Automation-Centric philosophy must now be adapted to develop the integrated controls system with fully automated (both interbay and intrabay) material movement systems.

2.2 Architecture Risks

Because most of the existing systems were not designed for full fab automation, not all of the required interface applications are well understood. As a result, we must decide to either integrate a number of legacy systems that were never intended to function together in this way, or to build a new software architecture with applications that can function robustly with one another. The I300I Guidelines and the 300mm Joint Factory Vision Documents point out the discrepancies that exist. Most MES, MCS, cell control, and AMHS vendors are evaluating the need for this new architecture and will move in that direction salvaging as much of the previous work as possible. In moving toward the "fab as a manufacturing center," many questions need to be answered concerning how things will operate together.

2.3 Scheduling Risks

Another area of potential risk is scheduling. In using a full material logistic system, the objective will be to supply a time window for each operation thereby making a computer-based lot schedule decision at every step in the automated, 300mm fab. In previous attempts, unfortunately, most comprehensive scheduling applications have been implemented with mixed reviews. In addition to the need for the scheduling of WIP and qualification lots, there is a need to manage reticles, schedule preventative maintenance and reschedule resources as a result of downtime. Very promising scheduling applications have been developed in recent years (e.g. AutoSimulation's RTD™ and PRI Automation's Leverage Scheduler™). The advantages of such scheduling must be proven over manual systems or other rules-based systems. There is also the need for continued integration efforts within the fab control systems.

2.4 Operational Risks

In addition to the software, architectural and scheduling challenges, there are many risks associated with the requirements and proposed methods of fab operational management. This is particularly a problem for fabs producing a diverse product mix at relatively low quantities per lot. One key operational decision, yet to be resolved, involves whether or not a wafer FOUP (Front Opening Unified Pod) should ideally have a 13 or 25 wafer capacity. The impetus for using a 13-wafer FOUP becomes clear when the projected average lot size for a given 300mm-semiconductor producer is much less than 24 wafers (e.g. three wafers).

Another objective of some start-up ventures is to use the 13-wafer FOUP to reduce the operator carrying capacity limit dictated by the National Industrial Occupational Safety and Health (NIOSH) organization's calculation (Meyersdorf and Padillo, 1998). This is the method of calculating distances moved and frequency and accumulating for a full shift to produce a number that is either above or below the human factor threshold. By using the 13-wafer FOUP, the belief is that the intrabay carrying can be done manually. This hasn't yet been proven, as the frequency of movement is now doubled to get the same output.

An alternative to the smaller, 13-wafer FOUP is the use of a mixed lot concept, which is more flexible and would allow the industry to use the 25-wafer FOUP. This concept is one in which multiple, small lots would be transported in a single FOUP. Such an approach would create significant challenges in the current fab system software and logistics. Although this probably would not occur in fabs producing commodity products, it could be quite common for foundries.

Other operational challenges involve the handling of non-production wafers, randomization of wafers, sorting and the FOUP management that will be required in the 300mm fab. So when all the risks are added together, the recent delays in 300mm implementation are not so surprising.

3 RISK REDUCTION APPROACH

Much has been written about the value of risk reduction, especially as it is applied to software project management. A progressive approach to reduce risks for software development was defined by Barry Boehm. The approach involves working in incremental steps or phases to reduce software development risks. A diagram of this model is provided in Figure 1.

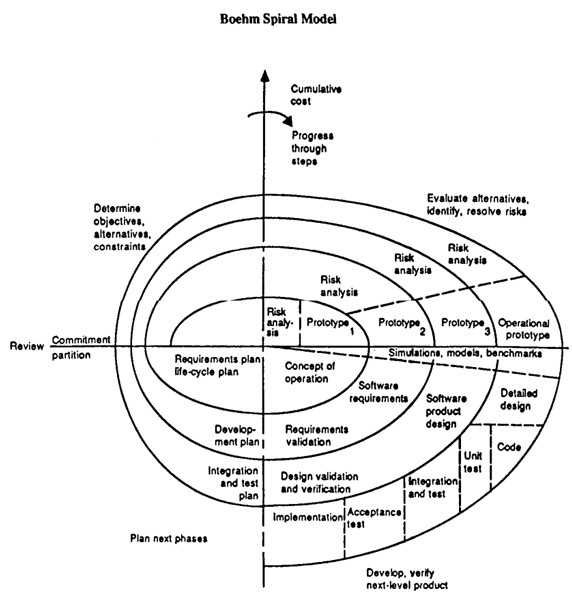

Figure 1: Boehm Spiral Model

In each phase of this spiral approach, the objectives and risks associated with those objectives are defined. Then the necessary sub-tasks or prototypes needed to resolve those risks are developed. Finally simulations and models are executed to verify that the objectives can be achieved.

The approach is initiated with a simple phased development concept and with appropriate prototype tests to ensure that the user ends with a completed, production-worthy system. A key advantage in approaching a complex project in this way is that the major risks are resolved at an early stage, before significant costs are accrued. In the event that some of the risks cannot be resolved using one approach, another approach may be pursued. In the event that the risks cannot be resolved at all, the project requirements may need to be modified so that a cost-effective solution can be developed.

What we are proposing is that a modified version of the Boehm spiral is used in conjunction with simulation to systematically address the risks associated with 300-mm development.

4 PROPOSED BOEHM SPIRAL FOR 300MM INTEGRATED LOGISTICS DEVELOPMENT

4.1 Phase 1 – Define the Operational Requirements of the Fab

The spiral model can be applied to 300mm logistics development for any fab problem set. However, in order to obtain the most general solution, we will consider the most challenging type of fab: a highly diverse, small lot size producer of embedded logic type devices.

In attempting to apply the spiral model to such an integrated logistics system, composed not only of software but also hardware, one issue arises immediately. Both the AMHS hardware and logistics software has been under development for a number of years, each with their own development cycles. For the AMHS these cycles have included prototype, pilot and pre-production cycles. The software has also undergone various evolutionary and revolutionary upgrades. Given this, how do we apply the Boehm model?

It is proposed that the first phase, or set of objectives, should involve defining how the fab will operate. It will then be necessary to document this approach as a functional requirement specification. This will then drive the logistics' system design. The problem is that when we begin to define how we believe the fab should operate, many questions arise concerning capabilities. Some of these concerns are risks that must be resolved before committing to a particular design implementation.

In Section 2, some of these operational methodology risks were outlined. One of the key risks involved the handling of small lot sizes. One approach to this problem is to use 13-wafer FOUPs. Many companies, including TI, Motorola, and Siemens have studies in process to determine the feasibility of using the 13-wafer FOUP vs. the 25-wafer FOUP. How can this be studied without complete production testing?

By using discrete-event fab simulation, the operational issues associated with this decision can be clearly understood. The advantage of using simulation, in this case, is that the effects of 13-wafer FOUPs vs. 25-wafer FOUPs on fab throughput and cycle time can be studied without building the system or modifying process equipment to accept 13-wafer FOUPs.

An alternative to using 13-wafer FOUP is the transport and processing of multiple lots/FOUP. One of the many operational and financial questions that must be resolved if this approach is pursued is, " Will using multiple lots per FOUP result in a significant increase in the number of reticles required in the lithography area?" This type of analysis again requires simulation modeling in order to understand the implications of this methodology on the number of additional reticles that may be required.

Another risk that needs to be resolved involves the application of fab-wide scheduling. This becomes another area where fab simulators and emulators can be utilized to validate the output capability of each approach. The objectives here may involve a comparison between a rules-based approach and an algorithmic approach versus the manual scheduling of the past. This could be accomplished via simulation by using a socket interface to the scheduler. This would allow the simulator to pass information to the scheduler regarding lot completion, resource status, etc. The alternative to this approach would be to experiment with the two scheduling methodologies in an actual fab. This would not only be expensive, but also very disruptive to fab personnel.

After all of the operational risks are resolved via simulation and modeling techniques the operational methodology for the fab can be developed. From this methodology a detailed specification of fab operational requirements can then be deployed.

4.2 Phase 2 – Validate the Requirements of the Logistics System

In the second phase of this modified Boehm approach, it is necessary to begin enhancing, modifying and validating the requirements for the logistics system. This includes all of the production software, MES, MCS, machine agents, etc. and the AMHS. At this point, a different set of risks begins to appear. From a customer standpoint, some of the major risks are:

- How robust is the material logistics (software and AMHS) system?

- With the I300I visions and guidelines, which specify the interface criteria, how do I prove that I have a fab-wide system that will work "out of the box"?
- Who is going to provide the integration of all of the interfaces listed in those guidelines?

From a development perspective, the risks might include:

- Definition of the true problem statement realized by the inability to communicate the needs and capabilities between the suppliers, the integrator and the customer.
- Determination of the cost of the attributes and payback on the solution. Cost might be the driver such that the true solution investment is unlikely.
- Demonstration and testing in enough depth to emulate a "fab-like environment."
- Resolution of problems and anomaly situations that will arise in the dynamic environment of the fab not accomplished during the development analysis.

A common approach to such development and integration in the past has been to simply develop the software, integrate the system and test it on the fab floor. However, there are several drawbacks to this approach. Problems that are uncovered in the post-integration, system test phase are costly to repair. This is especially true if the corrections involve changes in the system requirements and/or design. Moreover, it is often impractical to use the real system as a test environment due to the cost and time involved. Typically, there is time to run only a small number of test scenarios, so it is likely that some errors will not be detected.

A better approach is to use simulation as a test bed. Simulation could be used to test the system software during the design and integration phases. A detailed simulation model of the interbay transport system has been developed by one of the authors. This model replicates the MCS and AMHS controller logic. Any layout configuration can be modeled and simulated in a faster-than-real-time manner. By simulating many different layouts, the MCS and AMHS controller logic can be thoroughly tested in a relatively short period of time. As examples, simulation has been used to evaluate proposed MCS enhancements, uncover errors in AMHS vehicle routing algorithm, and discover events where the MCS and AMHS controller need to communicate to ensure good overall system performance.

Emulation can also be used as a software test tool. A detailed simulation model of just the interbay AMHS hardware has also been developed by one of the authors. This model has been linked to the actual MCS and AMHS system control software. Events in the simulation cause messages to be sent between the model and the system software. These messages have the same format as those that are transmitted in the real system. The emulator does not run faster than real time, but because the actual system software is used, errors in the controller code can be detected.

Building upon this technology, it is proposed that the scope of this emulator be extended to include process tools and complete integration with the logistics software system. The resulting system would then be an "Integrated Logistics System Emulator". Again, in order to reduce the risk and cost associated with this development, a Boehm cycle approach would be followed.

By developing this capability it will be possible to interact with the integrated logistics system in a dynamic environment, similar to that of an actual fab. The system is comprised of the following:

- Windows-like access to key production applications (e.g. MES, Scheduler, Transport Manager, etc.)
- AMHS/process tool simulator with animation that imparts production FOUPs, failures and other dynamic events similar to that expected in an actual production environment.

An example of the computer screen layout for such a system is shown in Figure 2. The elements shown include an animated intrabay AMHS with icons representing the various integrated software components. This system is implemented at the process module level (i.e. a group of process and support tools having a similar function, e.g. lithography) since the process module is the most basic unit of the fab involving the logistics system. The simulator portion of this system is designed generically, to handle any given type process module.

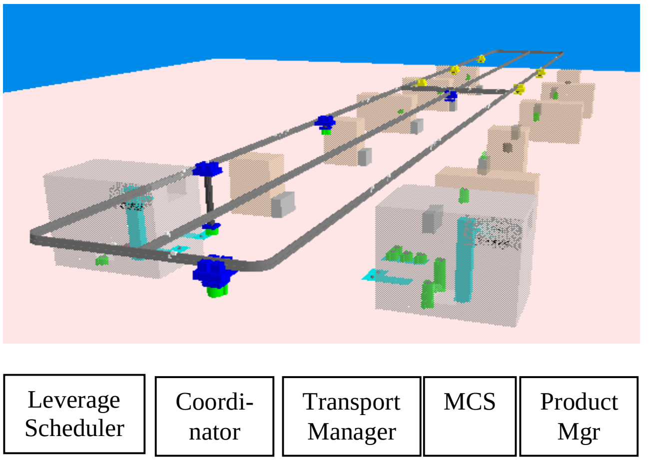

Figure 2: Example Screen Layout of the Integrated Logistics System Emulator

The Emulator architecture for the system is shown in Figure 3. With the exception of the AMHS/process tool simulator, the architecture of the system is the same as that of the real system. Note that the AMHS/process tool simulator connects in with the AMHS, MCS and Transport manager "emulating" the function of both the AMHS and process equipment.

The concept is that as the integrated system model executes, the virtual AMHS and fab respond to the simulated inputs. Such inputs involve various products introduced into the system, but also responses to the system, such as the need to put a lot on hold or a machine failing. Many events would require that users respond using the actual software interfaces. In this way, the user becomes very familiar with the system, even training with the system, before it is ever purchased or installed.

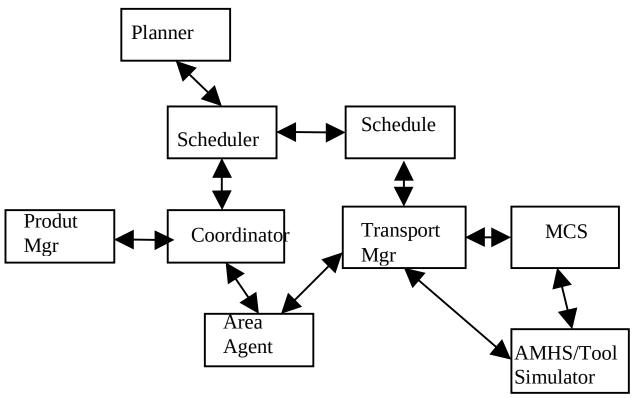

Figure 3: Architecture for Integrated Logistics System Emulator

In addition to providing the "look and feel" of the system for users, the system shown provides software developers and technical personnel with a powerful, integration test capability. This system allows development and operational personnel to follow message traffic and events between these applications and to "walk-through" various operations and scenarios. By building and working with this capability, it should be possible to validate the logistical system requirements.

4.3 Remaining Boehm Phases

Once the requirements are validated through the application of the emulator, the next phase is to complete the development process, which consists of changes to an already existing product. The major risk mitigation at this point involves integration with the actual hardware. This is necessary because of missed communication issues identified in previous integration efforts. As a result, additional integration efforts were required to ensure that loads could be transferred from one system to another. Also, because of the number of anomaly situations encountered, it was necessary to write much more code and to provide both computer assisted and manual work-around. Consequently, in this Boehm cycle we want to integrate the production software with the AMHS and process tool hardware as a process equipment test-line. After testing the system in this environment, the requirements for the initial production version of the integrated logistic system emerge.

The final phase involves refining and re-developing components of the system as necessary in order to implement a production-worthy system within an actual fab. Up to this point, the logistics system was not refined, e.g. error handling may have been defined such that all anomaly conditions were handled though software or manual work-around. Additionally, a number of problem areas regarding either the hardware or software functionality may have been noted. At this point the remaining risks simply involve the process of developing the production-worthy system. Using good software and hardware development processes can minimize such risks. These include such activities as detailed design reviews, unit and integration testing. Should the changes required in the system be very significant, then an additional test-line cycle may be required.

The final set of risks to be resolved in this cycle is the implementation of the logistics system within the fab. A key risk associated with this activity is simply the size and complexity of the task. Implementing the system in an incremental fashion can minimize this risk. An example of this might be the implementation of an interbay system with only two intrabay systems initially. After these systems "stabilize" the remaining bay logistics systems might be added incrementally.

SUMMARY

The implementation of 300mm, fully automated fabs is not a foregone conclusion. The reality is that there are a number of risks associated with the fab operational methods, software and hardware integration. Before such integrated logistics systems can be developed and implemented, these risks must be resolved. If these risks are not resolved, the potential for failure increases significantly along with the associated loss in invested capital. This is especially true for 300mm fabs that will be producing highly diverse and small lot size product mixes.

If we approach the problem of risks using the Boehm approach, then the risks could be resolved in phases, stages, and "bit-sized" pieces whereby some of the greatest risks are resolved before capital expenditures become very high.

In the first phase, key operational risks must be resolved. In the authors' view, not enough work has been done in this area. In order to execute this phase properly, the application of discrete-event simulation will need to be used extensively.

In the second Boehm spiral, it will be very important to be able to understand and to test the complete logistics system in a lab environment, where day-to-day production operations do not interfere with the development and testing of the integrated system. This can be accomplished via the integrated logistics system emulator. Again, in this role, the application of discrete-event simulation is a key component and enabler.

Even with complete Boehm cycles using simulation, the probability of major “show-stoppers” are minimized but the final unknown of volume testing cannot be fully realized without implementation. It is thus necessary to reduce and mitigate the known risks and then be flexible enough to handle the adaptations of the real system. This requires “close coupling” of the tool buffers, AMHS, MCS and MES which is the material logistics system and may eventually require a fully integrated solution as is now being offered by AMAT/Consillium/ AutoSimulations/AutoSoft or PRI’s fully integrated product suite.

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