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PROCESS AND MATERIAL HANDLING MODELS INTEGRATION

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ABSTRACT

AutoSimulations has developed and applied a new method of integrating separate models of manufacturing process and material handling systems that exploits the strengths of two different products to provide users with maximum productivity and flexibility. As applied to semiconductor wafer fabrication facilities in the examples presented here, this approach replaces the traditional method of building a single large, complex model of the entire scope of operations. Two case studies illustrate the technique and demonstrate the benefits of this new modeling architecture.

IBM recently contracted with AutoSimulations to upgrade an existing model of their prototype 300mm wafer fabrication facility. The existing model was developed in 1997 using the AutoSched™ application, a long-time manufacturing system modeling product from AutoSimulations. It incorporated various material handling systems (different configurations of overhead monorail layouts and use of operators) and manufacturing processes within one model – the standard practice for modeling wafer fabrication facilities with the intent of understanding material handling requirements and process requirements for varying order demand.

In 1998, Dominion Semiconductor, a subsidiary of IBM and Toshiba, contracted with AutoSimulations to develop a coordinated tool set to meet a diverse set of requirements to support their fabrication of 200mm wafers. The manufacturing support group needed assistance in planning process capacity, in planning future staffing requirements, and in analysis of cost reduction initiatives and production scheduling, including lot start and dispatch policies. The automated material handling system (AMHS) support group wanted a dynamic and graphical means of justifying new equipment and analyzing potential system modifications, as well as a tool to assist with other planning and daily system support activities.

AutoSimulations' solution for both projects was to integrate a detailed model of the automated material handling system, developed in the AutoMod™ software, with a manufacturing model developed in the AutoSched AP™ software, using a new product call the Model Communications Module™ (MCM). Material handling moves requested via messages by the AP model are executed in the AutoMod model. Other inter-model messaging coordinates processes in each model dependent on equipment availability or other material handling system conditions. Each model may also be run independently to facilitate specific uses by both groups.

1 INTRODUCTION

The current "standard practice" for modeling wafer fabrication operations as a whole is to develop a single model that encompasses the entire scope of fab operations. This effort and scope is necessary however to capture the constraining interactions of material handling and storage systems, process equipment, human operators and product flow throughout wafer fabrication. Due to the size these facilities and the enormous complexity of the wafer fabrication process, these models are typically very large and sophisticated. Months are often spent developing and validating these models. The models are applied to a variety of purposes, including facility layout planning, new equipment justification, staffing analysis, order dispatch and control management, and many other planning support functions. Their use has become integral to many business planning processes and in the daily operation of many wafer fabs, to the point of daily scheduling using "live" input data in some applications.

Various simulation software vendors have developed "templates" or entire products addressing the modeling challenges associated with semiconductor wafer fabs. AutoSimulations' flagship product for many years in this market was AutoSched. AutoSched provided a custom user interface, an existing customizable template model, and a dispatch rule editor. The product was built "on top of" AutoMod, a general-purpose simulation product providing built-in material handling constructs, a full-featured programming language and 3-D graphics. This architecture provided for data-driven models using AutoSched's input file structures and 3-D animation. One drawback to this broad functionality was execution speed. Addressing this issue, AutoSimulations' next-generation product, AutoSched AP, was optimized for runtime performance. The new object-oriented, C++ environment of AutoSched AP sacrificed the computationally intensive graphics for exceptionally fast execution speed. Many of AutoSimulations' clients were willing to live without graphics for the drastically improved model run times and other new functionality of AutoSched AP.

Recently (with the release of AutoMod version 8.7 in 1998) AutoSimulations has developed a product that provides for communication between different simulation models or between models and other applications. This technology is based on "sockets". Sockets communication is provided with most computer operating systems, and the TCP/IP standard allows for sockets on different hardware platforms to communicate seamlessly. Most computer systems have support for communications through TCP/IP Sockets. In Windows NT® sockets are called Windows Sockets, or WinSock.

Socket communications allow multiple models to be attached to each other via messages. This attachment can be between models on the same computer or with models on multiple networked computers. The messages may contain text information or data; the message formats are user-defined. The use of multiple models communicating saves time in model building, because different models can be developed concurrently by different simulation analysts, and instead of merging models or code, the models can work independently and communicate with each other where needed. This feature enables users to take advantage of using multi-processor hardware and networks of machines.

Considering the many opportunities now available given the ability for models to communicate with one another, the obvious new architecture for models of wafer fabs is to exploit the strengths of different products and link them via messaging. For the case studies described in this paper, the manufacturing systems (consisting of part routings, equipment definitions, dispatch algorithms, operations schedules, etc.) are modeled with the AutoSched AP software. The material handling systems (automated overhead electrified monorails, operators, storage units, operators, etc.) are modeled with the AutoMod software. The two models communicate via sockets with the Model Communications Module application. This design provides many benefits:

- Wafer fab process modeling in an environment specifically designed for that application, data-driven and extremely fast
- Material handling systems modeled with a full-featured simulation language containing built-in material handling modules and 3-D animation
- Independent model development, validation, experimentation and support
- Distributed processing, taking advantage of multiple networked computers or processors for improved runtime performance

2 PROCESS OVERVIEW

Wafer fabrication is an extremely expensive business. Typical fabs today cost several billion dollars to build and equip, due primarily to the extreme "cleanroom" environment needed to prevent contamination of the wafers during fabrication, the tight physical tolerances of the imbedded circuitry of the wafers, and the exotic production materials used. Many elaborate procedures and measures are taken to keep the wafers from being exposed to any dust or other foreign matter and all of the process and handling equipment is designed specially for cleanroom use. The equipment and fabs themselves also have a limited useful life due to rapidly changing technology and market forces. To be competitive in this environment, semiconductor companies need to closely monitor and control production processes and costs. Relatively small improvements, or problems, usually result in big cost impacts.

The processes involved in wafer fabrication provide many challenges. For example:

- Individual product routings are diverse and highly variable with frequent re-entrant flows (meaning the same sets of equipment are revisited many times)
- Changing priorities (the "what to work on next" decision) constantly require adjustments to schedules
- Time-critical interdependencies may interrupt planned sequences or lead to rework if time constraints are violated
- Different batching conditions at various process steps require complex dispatching decisions which may impact later steps (i.e. create starvation or bottlenecks)
- High quality standards necessitate frequent inspections and require periodic tool and operator requalifications
- Engineering tests and stringent handling requirements interrupt or delay equipment use
- Varying customer demand and new product introductions result in constantly changing product mixes.

All of these factors, along with normal process variations, create a very dynamic scheduling environment and a daunting environment to analyze or attempt to control. The need for automation (not to mention simulation!), both in the physical processing of product and in the control and management of the system is obvious.

The high level of automation and the many systems supporting production lead to the production of vast amounts of data. The need exists to better organize, make sense of, and present important information from this data in a systematic and timely manner for process monitoring, control and improvements.

3 MATERIAL HANDLING

Sets of wafers (referred to as "lots") are transported in sealed containers called pods. These pods, each containing up to 25 individual wafers, are stored within "stockers" inside each bay of the clean room. Stockers are automated storage units with an internal robot moving lots between I/O ports and shelves; the typical capacity of a stocker is about 200 pods. The pods are transported between the bays (isolated rooms connected to a central aisle) via an automated overhead electrified monorail system. The Dominion fab uses an AMHS provided by Precision Robotics Incorporated (PRI), which uses cars on the rail system to transport the pods. The movement of pods between bays is referred to as "interbay" transport. Figure 1 below shows the track layout of the PRI system. Each small loop extending from the central aisle (horizontal tracks in the diagram) services one or more stockers inside a bay.

The PRI system at Dominion currently services 11 bays on about 3,000 ft. of track, servicing 20 stockers (the AMHS simulation model included a planned expansion, which resulted in 39 stockers in 22 bays). Routing of cars takes place at redirection devices called turntables, which as the name implies, may rotate and proceed cars to different sections of track; there are 23 turntables in the system. Complex routing and parking migration algorithms determine the actual paths taken by the cars.

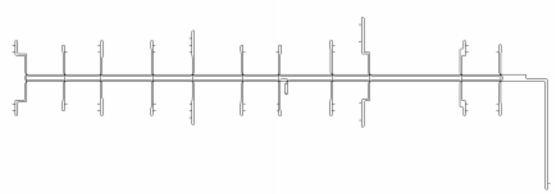

Figure 1: Dominion AMHS Plan View

For material handling moves inside each bay (so-called "intrabay" moves), human operators stock in and out pods from I/O ports at the stockers. At Dominion, the pods may be temporarily stored on racks inside the bay or used immediately on one of the machines in the bay. The racks in each bay act as local storage buffers to individual or sets of machines. The use and sizing of these local buffers is an ongoing process design issue at Dominion and is an important area of investigation.

The PRI system is controlled by Dominion's Material Control System (MCS), which communicates directly with the Manufacturing Execution System (MES). Together these systems track the location and status of each lot and OEM vehicle in the fab. The AMHS is supported around-the-clock (24x7) by on-site PRI engineers and a small group of Dominion engineers. The Dominion staff is responsible for recommending efficiency improvements, for new equipment justification and for ensuring the system is functioning properly to support production. A staff member is always on-call to address any problem that arises.

The IBM facility is the same basic "spine-type" layout as the Dominion fab. The exact type of material handling system was yet to be determined at the time of modeling, so rather than a specific vendor solution, various alternative material handling systems were modeled for comparative analysis. One system resembled the Dominion AMHS, another consisted of isolated interbay and intrabay monorail systems, another serviced the entire fab with an interconnected AMHS, and yet another consisted of a manual system. Each of the material handling schemes could be selected by flag settings in an input data file.

4 MODEL ARCHITECTURE

The system architecture provides the flexibility of separate use of the models and for tightly integrated operation. Running both models together (referred to as "integrated" mode) is necessary any time product routings, demand or mixes change. Both models' simulation clocks are synchronized, with the models communicating via messaging technology provided by the MCM. This mode is activated from the AutoSched AP environment, with that model acting as a "server" to the AutoMod "client".

Upon model start in integrated mode, a single data file is read by both models. This file contains definition information regarding the stockers and local buffer storages. The use of one input file for both models simplifies the change management of the storage devices, the only equipment common to both models (an operator input file may be added to the IBM model to handle dynamic sharing of operators for material handling and process tasks).

While running in integrated mode, the AutoSched AP model messages to the AMHS model when material handling moves are needed, then waits for the AMHS model to execute the move and return a message that the move was completed. A unique message type for each of these messages (signified by a particular *type of message* defined for the MCM) contains:

- the string name of the lot
- a lot pointer value (an integer)

- the string name of the local buffer the lot is moving from (if it applies)
- a pointer for that buffer
- the string name of the stocker the lot is moving from (if it applies)
- a pointer value, the string name of the stocker the lot is moving to (if it applies)
- a pointer value for that stocker
- the string name of the local buffer the lot is being sent to (if it applies)
- a pointer value for that buffer
- the priority of the lot
- a unique message number (for validation)
- an integer move type (1 – 4):
  Type 1 - a stocker to stocker move
  Type 2 - a stocker to local buffer move
  Type 3 - a local buffer to stocker move
  Type 4 - between two local tool buffers

When a move message is received by the AMHS model, a lot load is created, attributes are assigned as read from the message, and a material handling move is initiated. At times, the destination directed by the manufacturing model may not be available (i.e. the device may be down or in a maintenance mode), in which case algorithms in the AMHS model choose an alternate delivery destination. Once the move is completed, the AMHS model sends a new message to the manufacturing model. This message returns most of the data originally sent (for validation by the AutoSched AP model and retrieval of the proper delayed lot) along with a flag indicating whether or not the lot arrived in the destination directed by the manufacturing model. If the lot did not make it to the "primary" destination, a list is updated for later "migration" moves (explained below).

A third type of message is defined for the AMHS model to signal the AutoSched AP model any time a storage device returns to service after being down or now has available capacity after having none. This message simply passes the string name of the device back. The manufacturing model recognizes this type of message as a signal that it may be able to request "migration moves" from alternate storage devices to their "primary" destinations. A list the model has kept of lots not reaching their primary destination is searched for any that may need to move to the newly available storage device and new move messages to that effect are issued to the AMHS model.

Figure 2 shows the relationship of the models and their data files. Although the messages are depicted as travelling via a network connection, the models may in fact reside on the same computer. Two output files are generated by the AMHS model during "integrated mode" operation. They are both flat ASCII tables of "from/to" average move rates and durations.

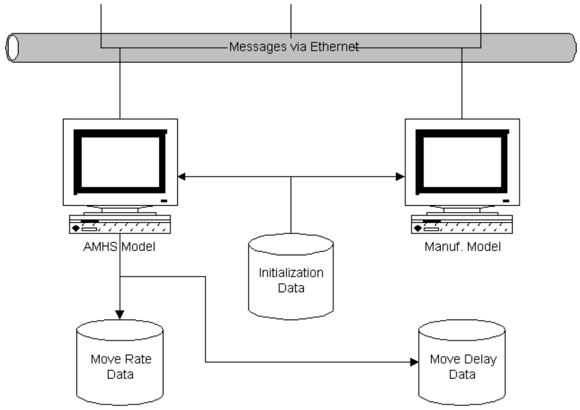

Figure 2: Integrated Models Schematic

The from/to move rate and duration tables generated during integrated use of the models provides the capability to later drive each model separately (see Figure 3). If operated independently, the AMHS model may use the from/to rate data to generate moves independently. These rates may also be factored (using some rate multiplier for instance) to induce more or less overall load on the AMHS. Other, separate experiments may be performed with the AMHS without the need to run both models together.

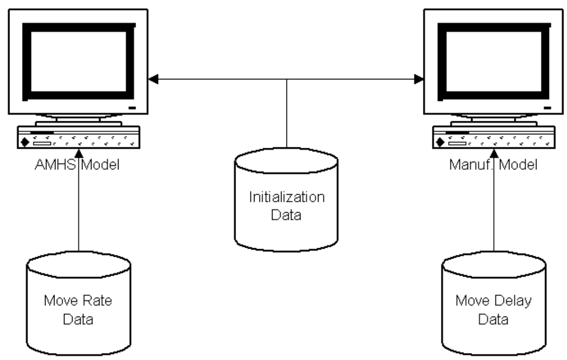

Figure 3: Independent Models Schematic

Independent running of the manufacturing model provides the best runtime performance and is used for long time-horizon experiments (cycle time studies, for example). Average delay times for all from/to combinations generated in integrated mode are used to model typical delays encountered in material handling. The use of the delay times can also be defeated entirely to compare simulated overall cycle times to ideal total process times. Updates to the rate and delay files are made any time a routing, product mix, or equipment change is made to either model.

In addition to the flexibility of use, this architecture provides the capability of supporting each model separately. The AMHS support engineers at Dominion use and maintain the AutoMod model independently of the

Process Support Group; the process equipment and automation support engineers at IBM are at different sites. Independent use also provides better skill mapping to each application. The modular design is highly extensible, an important factor in the planned on-line integration of the models (see Figure 4).

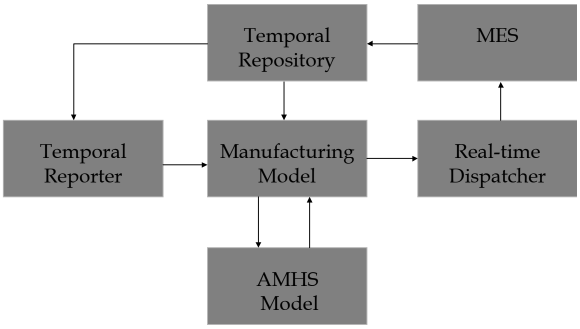

Figure 4: Potential Systems Integration

5 CURRENT STATUS

The AMHS engineers at Dominion are currently using the system to justify new stocker requirements and determine the optimum number of cars under various operating scenarios. They are also analyzing the cause of vehicle gridlocks and other control system issues.

Process support IEs at Dominion are currently using the models to identify and analyze capacity constraints in the fab. The effectiveness of adding local buffering (racks for staging pods inside the bays) is also being evaluated. New or modified dispatch policies are being tested in attempt to reduce WIP and reduce cycle times.

Dominion cost accountants are anxious to apply costs to modeled activities to better evaluate proposed process changes and cost reduction initiatives. They see this tool as a new and better way to determine whether or not local improvements have a significant effect on “the bottom line” – in other words, whether spending money on improvements in particular areas or processes returns the investment from an entire process-level perspective.

IBM engineers are using their AMHS model to evaluate the efficiency and tradeoffs associated with different material handling system designs. Many new handling issues are becoming significant concerns with the design of 300mm wafer facilities, such as the higher costs of wafer damage during handling and ergonomic constraints imposed by the larger and heavier pods.

Process planning and facility engineers at IBM are currently using the models to determine tool set requirements for various production rates and product mixes. Different layout patterns are being compared for space requirements, and overall effect on throughputs and product cycle times.

6 POTENTIAL INTEGRATION

Upon completion and validation of the manufacturing and AMHS models, Dominion management decided to move forward with further integration and development of the models with other AutoSched Productivity Family™ (APF) products and their business systems. Temporal (time-based) archival and reporting capability will be added with the ISS Reporter™ application. This technology provides a powerful means of capturing MES transactions in a temporal database and creating ad-hoc custom reports and business graphs of fab activity. Because the repository is temporal, reports can be developed that cannot be created using traditional databases, which simply store “snapshots” of shop floor status, not a complete history. The tool may be used to “drill-down” to the specific cause of problems to determine the root cause of reported anomalies.

AutoSimulations’ Real-Time Dispatcher (RTD) ™ product is in the process of being integrated with Dominion’s MES (refer to Figure 4). Once complete, fab dispatching rules may be developed and tested using the manufacturing model, then safely implement into the MES scheduling system for real-time dispatching based on the current status of the fab. The RTD application will be seamlessly integrated within the MES so that operators will continue to see the same dispatch screens as today.

In the future, Dominion may chose to integrate the AMHS control system (MCS) into the architecture. This addition could further refine the dispatching and control of vehicles in real-time based on current conditions. Plans for this enhancement have been postponed until the APF components are functional.

At the time of publication of this paper, IBM management was considering a proposal by AutoSimulations to further integrate the manufacturing and AMHS models with the APF tools.

7 SUMMARY

The integrated model solution provided by AutoSimulations is an effective way to model separate, but inter-dependent business functions. Applying the “best-fit” tool to its particular strengths, and linking the tools with messaging technology, increases flexibility and productivity throughout the project life cycle. Use of a common input data set for both models facilitates consistent application of input information and provides for future live integration of MES data.

Independent use of each model provides the capability for detailed analysis and experimentation with the AMHS model, and extremely fast execution of the manufacturing model for scheduling and capacity analysis. The individual models may reside in different physical locations, connected over the company’s network, an important aspect since personnel involved with these projects come from different organizations in different physical locations.

The model architecture has proven effective and versatile; it could be implemented in a wide range of similar applications.

REFERENCES

Barksdale, J., Norman, M., Tinsley, D., Wiersholm, O., 1999. Integration of Manufacturing & Material handling Simulation Models. *IIE Simulation Solutions '99 Proceedings.*

Rohrer, M., 1998. Vision of Emulation, *AutoSimulations Symposium '98 Proceedings.*

Stafford, R., 1998. AutoMod/ASAP Integration, *Auto-Simulations Symposium '98 Proceedings.*

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