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SIMULATION IN THE DESIGN OF GROUND-BASED INTRABAY AUTOMATION SYSTEMS

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ABSTRACT

Material transport within a semiconductor factory (fab) can be broken into two categories - interbay (bay to bay movement) and intrabay (within bay) movement.

Due to the fragile properties of semiconductors, there are risks associated with any movement of material. These risks range from misprocessed or damaged wafers, to throughput loss. These risks are increased during manual intrabay handling, where several operations may be taking place in a populated, confined area.

Intrabay automated material handling is a means by which the above-mentioned risks can be reduced or eliminated. Simulation can play a key role in the design of intrabay automation systems, in verifying that the system will not negatively affect throughput of an area.

A simulation model has been developed to analyze the effects of intrabay AMHS on a manufacturing bay. Model architecture is discussed, and three case studies demonstrate applications of the model.

1 INTRODUCTION AND OVERVIEW

Automated material handling systems (AMHS) in semiconductor factories can be separated into two classes - interbay and intrabay. Interbay systems are large, factory wide systems which move materials between bays or functional areas throughout the factory. Interbay systems are typically monorail-type movement systems, where vehicles move material using the monorail and interface with AS/RS machines (stockers) in areas where materials are processed (manufacturing bays). The advantages of simulation in the design of interbay systems have been documented in the past. Pillai (1989) showed how simulation can be used for design verification and sizing the different components of the total system. Nadoli and Rangaswami (1993) presented a modeling methodology for simulating interbay systems.

Intrabay material handling systems are specific to one processing area or bay. These systems, which move materials directly to and from tools within a bay and load and unload equipment, allow for better tracking of materials, more reliable material handling, and reduced overall system variability for even the most complex operations. Cost savings can also be realized by reducing the manpower required to run a bay, improvements in ergonomics and overall cleanliness.

An automation system typically consists of a shop floor controls system communicating with an AMHS and an automated equipment control system. Figure 1 graphically depicts this automation architecture.

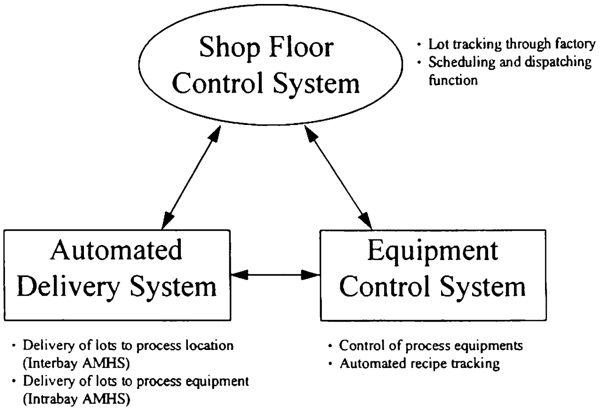

Figure 1: Intrabay automation architecture.

The shop floor control system communicates with the AMHS and provides information on lot delivery locations. In addition, an intrabay automation system requires a tight coupling between the delivery mechanism and the equipment control system.

In a full factory setting, these complex interactions are very difficult to predict; hence, requiring the use of a simulation or modeling tool. In addition, the manufacturing process may also include constraints whose effect on factory output become difficult to predict. At Intel, the Material Handling Systems Simulation Group simulation has built a suite of modeling tools that can be used to model and predict the behavior and performance of the AMHS in a full factory setting. An intrabay modeling methodology has been developed where a core model interacts with add-on components to create a flexible tool that can be configured, based on the type of processing equipment which is being automated, or the type of outputs which need to be collected. This approach has led to a tool which is both powerful and easy to implement. All the simulation models used within the group use AutoMod II (AutoSimulations, 1992) as the simulation tool environment.

The remainder of this paper will describe the modeling methodology and present applications, in the form or case studies. Section 3 details the model architecture, and discusses both the model core and the add-on approach to the model. Section 4 presents 3 case studies which demonstrate applications of the model. Section 5 lists conclusions, and areas of possible future study and application of intrabay automation.

2 AMHS SIMULATOR ARCHITECTURE

The Intrabay AMHS simulation model consists of a core model and four major sub-sections, or modules, graphically depicted in Figure 2, below.

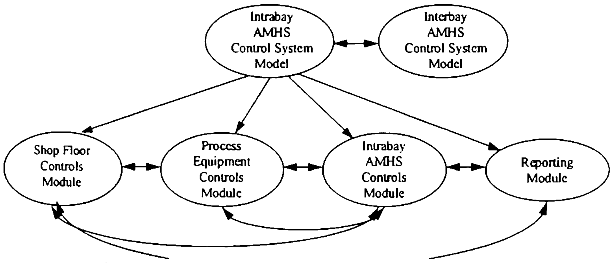

Figure 2: AMHS Simulator Architecture

2.1 Shop Floor Control Module

This module includes code which simulates the WIP scheduling rules that are built into the Shop Floor Controls Systems. Different WIP management rules, such as Theory Of Constraints (TOC), Just-In-Time processing (JIT), etc. can be simulated.

2.2 Process Equipment Module

This module includes details of the process equipment being modeled, such as its speed, setup time information, batching characteristics, equipment buffer configurations, and the amount of re-work being processed.

2.3 Intrabay AMHS Module

A typical Intrabay AMHS consists of a storage system and a transport system. This module simulates all the interactions that happen between the different AMHS components, including transport to the process equipment. It can also include AMHS reliability information, and can interface with an Interbay AMHS model to simulate lot movement between the different parts of the factory.

2.4 Reporting Module

This module includes software to provide output reports and charts. These reports include the standard reports provided by the simulation tool as well as custom reports which provide more information on the performance of the AMHS.

The simulation software in these modules has been written in such a way that it can be easily modified in the event of changes. For example, the Intrabay AMHS module can be changed to model the characteristics of different variations of AMHS, without modifying too much code. Another feature of the Intrabay model is that much of the information is present in different data files. These files can be easily changed to perform sensitivity analyses to understand the effects of different input parameters. This paper will now show how this modeling tool has been used to model three different variations of intrabay systems within Intel's wafer fabrication facilities.

3 CASE STUDIES

3.1 Simulation of Diffusion Intrabay

Figure 3 shows a typical layout of an intrabay AMHS in a diffusion processing bay.

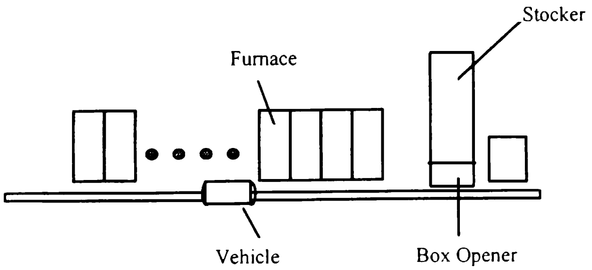

Figure 3: Diffusion Intrabay line

The system consists of an automated storage system (also known as a stocker) communicating with a ground-based robotic vehicle, capable of carrying multiple loads, which delivers lots to the diffusion process tool. The stocker also provides an interface with the Interbay delivery system. Diffusion operations are batch processes, with up to 6 lots being loaded into the tool. In addition, the tool has a buffer which can hold one extra batch.

The objectives of the simulation model were to determine the time needed to deliver a batches of lots to the furnaces at different factory wafer start loading conditions, and to determine the utilizations of the different AMHS components (stocker robot, stocker storage, and vehicle utilization). Figure 4 shows the variation of the batch delivery time with the loading of an Intrabay line.

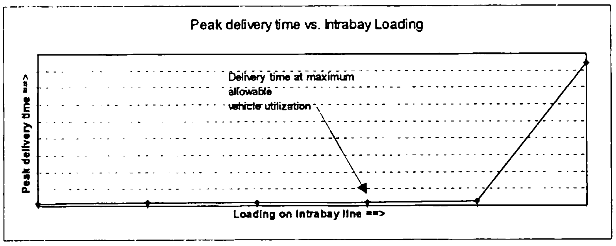

Figure 4: Batch Delivery Time to the Tool vs. Loading on Intrabay Line

Figure 4 shows that the batch delivery times remain constant up to a certain level, beyond which the delivery times increase almost exponentially. Figure 5 shows the utilization of the robotic vehicle.

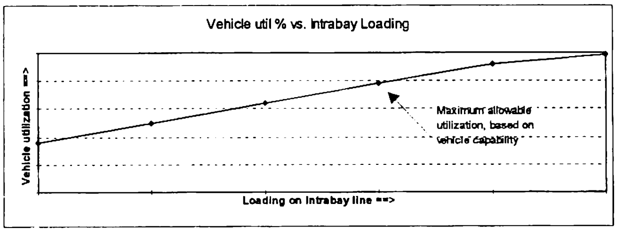

Figure 5: Vehicle Utilization % vs. Loading on Intrabay Line

Figure 5, when combined with Figure 4, shows that the delivery times begin to increase when the loading on the robotic vehicle increases beyond its capable limit. This defined the maximum allowable throughput capability of the Intrabay line.

After the system was released to production, the different AMHS components were monitored. The validity of the simulation model was confirmed when the delivery times seen with the actual equipment closely followed the estimates provided through the dynamic simulation model.

3.2 Intrabay in Lithography Processing

The process of lithography (litho) is the most critical processing in semiconductor manufacturing. Due to the intricate nature of litho processing, these tools are very expensive, costing millions of dollars. When investing such a sum in equipment, a high priority is placed on attaining its maximum utilization. Intrabay automation was seen as one way to help increase tool utilization and reduce equipment costs.

The model used to model diffusion intrabay automation was used as a baseline to simulate an automated environment. The diffusion model was viewed as the core model, as it had been proven to be an accurate simulator of actual diffusion operations. However, differences between diffusion operations and litho operations such as batch size, processing time, layout of equipment, and lot buffering led to additions to the model which built upon this core and added to the flexibility of the model.

The spin, expose, and develop processing sequence performed by a litho tool is shorter in duration than diffusion processing, and therefore the time to deliver materials (the time between processed lots) could negatively impact tool utilization. As a result, the number of lots at the tool waiting to be processed - the buffer size - becomes a factor in AMHS design. If a tool has too small a buffer, the tool could be starved for material to process, negatively affecting tool utilization.

Two new functions were added to the model to provide for the new requirements brought on by lithography processing. First, the way in which lots requested the vehicle was modified. The structure of the model was modified to work in the following manner. Once a lot arrives at the stocker, it first checks to see if there is a location available on a tool before attempting to move to the tool. If a location is available, the lot will claim it, and then initiate the sequence of steps needed to move from the stocker to the tool port. If no buffer location is available, the lot will continue to search for available locations, until one becomes available.

The second addition to the core model was to include tool processing time into the scope of the model. The addition of processing time enabled the utilization of the tool to be measured, and in turn the effect of buffer size on tool utilization could be observed. Each tool port (buffer) has its own queue, with a capacity of one lot, and lots in these queues attempt to obtain a resource (the tool), also with a capacity of one. A lot holds the resource for the processing time, then releases it to be claimed by other lots waiting to use that resource. It should be mentioned that, in keeping with the goal of flexibility in the model, all of the changes made to accommodate litho tool modeling are configurable. Also, the model can revert back to its diffusion format by changing input flags.

Once the above-mentioned 'add-ons' were complete, simulations were run to determine the effect of buffer size on tool utilization. Each simulation run had the same inputs for throughput level, tool processing time, and number of tools on the intrabay line, with buffer size the only variable. Four scenarios were simulated, with the buffer size ranging from zero to three. Results of this experiment can be viewed in Figures 6 and 7, below.

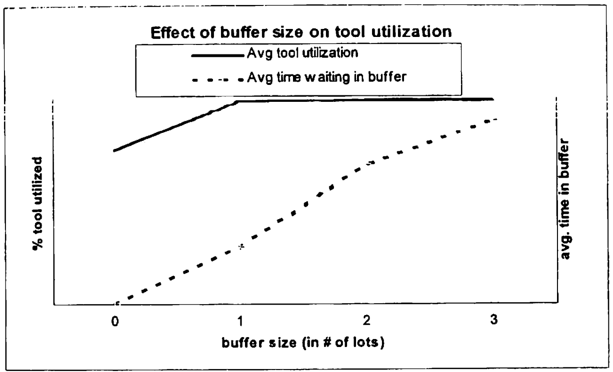

Figure 6. Effect of Buffer Size on Tool Utilization.

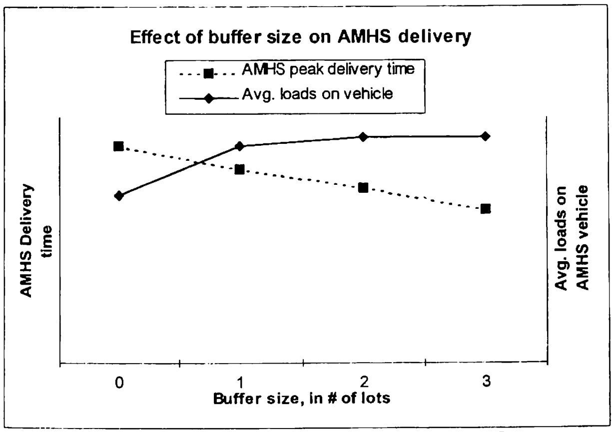

Figure 7: Effect of Buffer Size on AMHS Performance.

Figure 6 shows the results generated by the model to determine the effect of buffer size on tool utilization. Figure 6 also shows the average time spent in buffer as a function of buffer size. The analysis suggests that utilization of the tool will be significantly afftected if there is no buffering, and there is no gain in tool utilization by adding more than one buffer location.

Figure 7 shows the effect of buffer size on the ability of the automation system to transport lots to tools. Two metrics are shown, delivery time and the average lots on the AMHS vehicle. A decrease in delivery time was observed as a result of increasing the buffer size. This decrease can be explained as a result of the AMHS vehicle having a greater opportunity to carry more than one lot, which led to more than one lot delivery of materials for a typical cyclew, and thus shorter delivery times per lot.

From these results, it can be seen that although increasing the buffer size beyond one does not increase tool utilization, an increase will result in better AMHS performance and more 'flex' in the overall system. At this point in time, it is too early in the project to validate these results against an actual running system. However, the model used contains the same core software as the diffusion model, which has been validated against actual performance. The ability to re-use the core software of another model which has been validated is another example of the benefits of the core/add-on methodology of automation modeling. For the same reason, this approach has also been adopted for additional intrabay automation simulation studies, described in the next section.

3.3 The Value of Simulation in Analysis of Future Intrabay Systems

The analysis of future applications of intrabay automation has concentrated on the use of value engineering to perform analysis quickly, to keep up with changing process requirements. As in previous intrabay analysis, models were utilized to filter out the highest priority tools based on the benefits of automation, the return on investment, and the compatibility of automation. This filtering process is shown graphically in Figure 8, below.

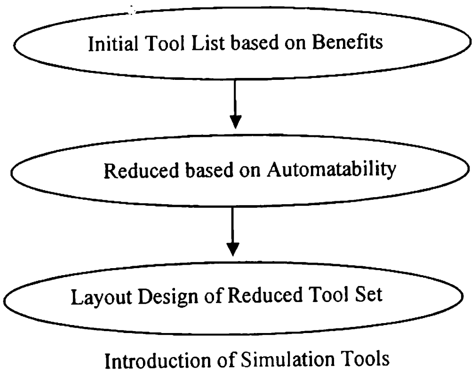

Figure 8: Filter Process Used in Determination of Functional Areas to Automate

Once the filtering process has been completed, the next steps are to once again look at the intrabay layout configuration and automation requirements. From a layout perspective, it is necessary to determine if the tools can be positioned for effective automation access, without violating safety, microcontamination, and ergonomic guidelines. These intrabay-inclusive layouts must also be re-verified to ensure that all process performance requirements are met. It is at this point that the value of the simulation model is exhibited.

In the first case study of diffusion, the performance requirement was based upon the batch delivery time from storage to tool port.. Then, in the case of lithography, analysis was delivery time based with an additional emphasis placed upon tool buffer requirements. In modeling new intrabay options, the initial focus was again on delivery time performance within the design parameters of the intrabay automation equipment. The key to success will be the rate at which the simulation core model, using existing add-ons, will be implemented for two different functional areas of the layout. As seen in Figure 9, the reduction in time to deliver the model results has greatly increased the flexibility to consider new process requirements for run rate and tool quantities.

Model	Simulation Software Development Time	Analysis at Implementation
Diffusion: Case Study #1	~ months	- delivery time
Lithography: Case Study #2	~ weeks	- delivery time + buffer, tool utilization
New Intrabay: Case Study #3	~days	- delivery time + buffer, tool utilization + ...

Figure 9: Time to Simulation Implementation

Using the methodology shown in Figure 8, it has been decided that two areas of processing, thin films and plasma etch, may be best suited for intrabay automation. The initial layout of these bays with intrabay automation are similar to the layouts seen in diffusion. Characteristically, thin films tools are larger in foot print and have faster run rates. Therefore, due to the nature of these functional areas, a variable number of tools per line must be considered in the layout verification process. (Figure 10).

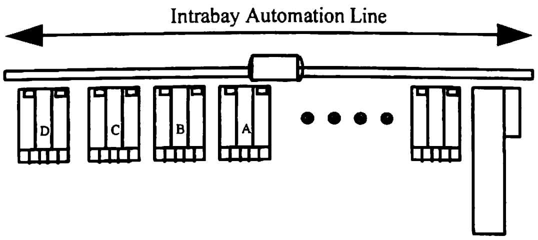

Figure 10: Layout Configurations Considered for Simulation

The purpose of the simulation study therefore is to verify the feasibility of each process tool and its layout when coupled with intrabay automation. The key indicators once again were batch or lot delivery time, and the throughput requirements of the intrabay vehicle.

Figure 12 exhibits that although the etch equipment modeled can support a larger number of tools per intrabay system, the faster run rate of the thin films tools requires more AMHS deliveries per system. As expected, the higher activity rate for the thin films case in turn resulted in slightly longer delivery times per system, as seen in Figure 11. Although the length of these bays is very similar, the tool interface requirements for automation have contrasting differences. These differences, coupled with manufacturing operating requirements, could lead to a modification of the layout to keep the batch delivery times within desired limits.

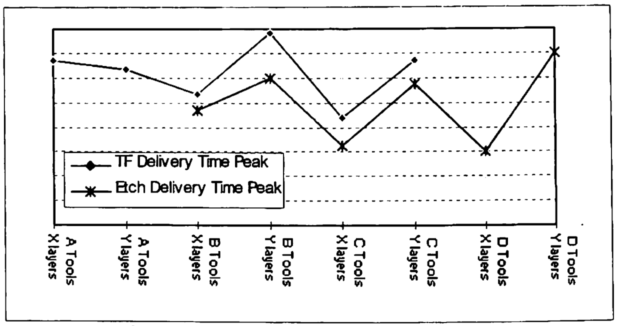

Figure 11: Lot/Batch Delivery Time

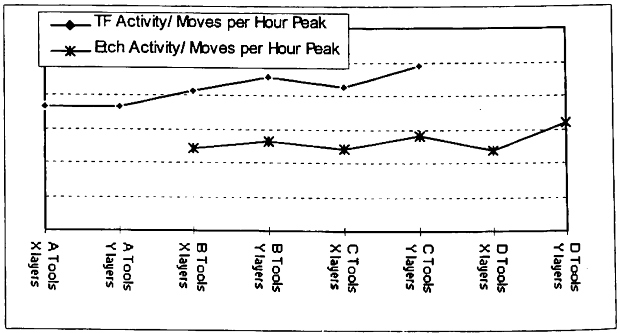

Figure 12: Intrabay Vehicle Movement in Lots Moved Per Hour

These types of sensitivity analysis will be performed through modification of existing simulation software or via the creation of new software modules. Additional data analysis will include the effect of operational assumptions on tool utilization. Ultimately as was done (or is going to be done) in the previous case studies, all model results will be compared to the actual field data after installation.

4 CONCLUSIONS AND FUTURE SCOPE OF WORK

4.1 Conclusions

The Intrabay simulation model has proved to be very useful in designing automated Intrabay systems within Intel's wafer fabrication plants. The same tool has been used to model different processing areas without any major simulation code modifications. We have successfully utilized this modeling approach to understand system behavior in three different processing areas. As an additional benefit of using this modeling approach, we have been able to reduce the modeling cycle time, from months to days. The reduction in development time can be attributed to the overall modeling methodology and the structured model interfaces that were built to support this methodology. We estimate that we can now develop simulators for a new vehicle control system in a matter of days.

4.2 Future Scope of Work

To date, we have utilized this simulation model for modeling 200mm toolset intrabay material movement. With the transitioning of 200mm to 300mm wafers comes new opportunities for automation and layout design. These options will likely be studied and evaluated in the existing 200mm arena, and will require data to support their consideration.

Therefore, the core and add-on approach to simulation will be called upon to incorporate modules for new controls software and new interface requirements for interbay material handling systems. Other possible modules will address additional changes that may be developed from the continual improvement process. These changes could include intelligent vehicle controls and work rule scheduling methodologies. Systems like these are already in development.

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