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ANCILLARY EFFECTS OF SIMULATION

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ABSTRACT

Simulation can often be one of the first modeling tools implemented at a manufacturing site. When this occurs, much effort must be used to get current manufacturing data into the simulation model. The amount of time and data needed to get the simulation running to an acceptable validation level and to maintain that validation level over time, should lead to an effort to automate the loading of factory data into simulation. If this automation effort is efficient and comprehensive, it can become the cornerstone of a system that benefits manufacturing from more than just simulation analysis. The other benefits range from the development of a simple times theoretical analysis of the line to the complex development of an infinite capacity planning system. This paper will discuss a real world example of the extra benefits received from implementing simulation at a semiconductor manufacturing plant.

1 INTRODUCTION

MOS 12 is one of Motorola's semiconductor wafer fabrication plants that produces microcontroller devices. As an integrated circuit semiconductor wafer fab, MOS 12 has hundreds of products that each consist of a couple of hundred steps that require about one hundred or so different equipment types to produce. The total cost of such equipment is over 1 billion dollars. In addition to the number of steps required to build each product and the number of products, more complexity is added because the product flows are recursive with some equipment types being visited multiple times. The worst case scenario is that some equipment type will be required fifteen to twenty-five times during the process flow. These complexities make modeling a semiconductor wafer fabrication plant extremely challenging.

Due to the above complexities, MOS 12 chose to implement a discrete event simulation model to help evaluate manufacturing performance issues. Discrete event simulation was recognized as a tool that could model such a complex system because it could evaluate the interaction between product mixes, taking into account time dependencies from recursive flow, and the stochastic nature of events in manufacturing.

A. Alan B. Pritsker, in *Introduction to Simulation and SLAM II* (1995), establishes 4 main performance measures for manufacturing systems. These are throughput, on time delivery, resource utilization, and in-process inventory. Since the building of the first model in 1994, discrete event simulation has been used successfully to evaluate these performance measures for different manufacturing scenarios. An example of typical scenarios evaluated include mix analysis, start rate increases, equipment install prioritization, optimal wait time at an equipment type for batching scenarios, and automated material handling system issues.

2 INITIAL MODEL BUILD AND VALIDATION

The building of the first model consisted of defining the system based upon the above outputs required for evaluation. A system is essentially a grouping of elements that interact together through some logic to complete a task or goal (Law and Kelton 1991). The elements for the defined system were chosen to be equipment, product, guided vehicles for product movement, and product stockers. Equipment was defined by what was currently in each bay of the fab. Product was defined with part names and each product has a series of steps it must go through to be completed. Each step has a defined recipe that runs on a defined equipment type with a setup and processing time. Guided vehicles were defined as the method of moving product from one bay location in the fab to another bay location. Product stockers were defined as the place in the bay where the guided vehicles delivered product. After defining the system, some analysis was done to understand what types of data needed to be collected for each entity in the system. The basic data needed for input to the model were:

1. Equipment performance data
   - List of active equipment types

- Number of equipment for each equipment type
- Equipment state fail and repair characterization
- Equipment processing type (singular/ batch/batch sequential)
- Recipe throughput data for equipment

2. Part/Product data
   - Path/route product will follow for processing (including alternates)
   - Recipe to be run at each step (including alternates)
   - equipment for each step of route (including alternates)
   - yield data at each step of process
   - start rate data
3. Guided vehicle
   - Defined available paths
   - Travel time from stocker to stocker
   - Number of guided vehicle
   - Capacity of guided vehicle
4. Material stocker
   - Capacity of stocker

The data for the above system was collected from the MOS 12 CIM (Computer Integrated Manufacturing) System. Scripts were written to help extract the information needed to build the model. Product information was extracted from the WIP tracking system called PROMIS (a product from PROMIS Systems Corporation). Equipment information was extracted from a Motorola internally developed equipment tracking system called SEPT. The material transportation information was collected from another internally developed Motorola system called the Material Control System (MCS). It is important to note that for the initial model build the extraction of the data might have been a piece of code or script, but the data still had to be manually entered into the model. Also not all data was available in the systems and portions of the above data had to be manually calculated and entered. The attempt was made to extract as much input data as possible from the existing factory systems.

After the building of the first model, the initial validation was done through collecting historical factory data from the same MOS 12 CIM systems. More specifically this meant getting product performance data from the PROMIS WIP tracking system. It also meant getting equipment performance data from the SEPT equipment tracking system, and it meant getting inter bay delivery data from the material control system.

Programming scripts were written to help collect the data from the systems. Much of the data was in raw format and had to be manipulated to give summary data that was comparable to the simulation output. Also, the actual validation task still had to be accomplished through manually comparing factory data to simulation data. The basic types of validation data collected from the factory systems were:

1. Equipment data
   - WIP
   - Throughput
   - Utilization
   - Cycle time
2. Product data
   - WIP
   - Yield
   - On time delivery
   - Cycle time
3. Material movement data
   - Bay to bay delivery times
   - Stocker inventory

The method of developing and validating the first MOS 12 discrete event simulation model was an arduous task, but the results left us with an accurate representation of manufacturing line to measure performance. Unfortunately, as the factory ramped up with new products and new equipment, it became harder to keep up with the new changes using the manually established model building process. The model started losing its validity and therefore, its credibility. At a certain point during the ramp up of the wafer fab, it became evident that the previous model building process could not keep the inputs to the model accurate. Failure to maintain good inputs to the model makes it impossible to generate a model that can mimic the real system and impossible to generate a model that can be validated.

3 INTEGRATION AND AUTOMATION

The loss of a model’s credibility to the customer makes the model useless. New methods for getting data into the simulation model needed to be developed. The goal was to automate and integrate the model building process. Integration refers to directly updating the required simulation input files with accurate factory information. Automation refers to the extraction of the factory data for input to the simulation and for validation of the simulation output. This extraction must occur on a timely basis (mostly determined by the model customer) so that it can be integrated into a simulation model.

The task of integrating and automating was broken down into the two parts. Part one dealt specifically with the collection of input data for the simulation. Part two dealt with the collection of validation data to compare with the simulation output data. The method of integrating and automating relied mainly upon the writing of programs to interface with the WIP tracking system, the equipment tracking system and the material control system. Due to the platforms on which the factory systems operate, the programs were of different types. Table 1 shows the different programming languages used to integrate the data from the extracts and automate the running of the extracts. The use of so many languages often make the extraction complicated, but this is unfortunately sometimes a reality in wafer fabrication plants.

Table 1: Program Languages Used

VAX	UNIX
DCL	KORN SHELL
FORTRAN	AWK
PROMIS SCRIPTS	C

The first type of input data to be automated and integrated was the product flows. All active factory parts are extracted from the factory WIP tracking system. These flows are then matched up with a maintained recipe information database. This recipe information basically contains theoretical processing time information for each recipe along with additional delays for setup and special processing (batch sequential) if required. Unfortunately, this information was not available from the existing systems and because of this, a separate database was required. The matching up of the flows with this database results in a table of all active parts and an accurate representation of every part's flow through the line with the addition of theoretical processing time at each step of the flow.

The next set of input data to be automated and integrated was the active equipment information. This involved extracting the equipment type, equipment id name, and the number of equipment that are currently active for manufacturing. This data is maintained in the equipment tracking system. This information is then combined with a manually maintained set of data that contains detail facts on the equipment. This detail pertains to the type of processing the equipment performs. The main types of processing were per wafer, per lot, multiple lot batching, lot sequential, or batch sequential processing equipment. It also pertains to the location of the equipment in the wafer fab and a brief description of the equipment. Minimum and maximum batch sizes were detailed. In addition to these, the dispatching algorithm used in day to day lot selection was identified. This results in an accurate picture of all equipment on the manufacturing floor and a basic description of how each piece of equipment is operated.

After getting the equipment information data, the next set of input data needed dealt with equipment state changes. This involved using the previously obtained active equipment list and extracting performance details from the equipment tracking system. The extracted data is then converted into different outputs. The first output contains information on mean time to fail and mean time to recovery for all equipment states and an estimate of the what distribution for each is. This information is then read into another program that converts the data into a formatted input for simulation. The second output simply contains the percent time in state for all equipment states. Both sets of output data are maintained for any time period requested, but standard period reports have been established for reporting purposes.

With much of the input data automated and integrated, the next step was to start looking at factory data to automate the validation of the output data from simulation against actual factory data. The first set of output data to validate is the part performance data. This involved extracting part inventories, cycle time, and yield for the whole line. This data is maintained in the WIP tracking system. Also maintained in this system is the equipment performance data with respect to product. This data is the average cycle time to process at an equipment type and also the average WIP at the equipment type. The cycle time data is important to have broken down to the recipe level for validation of theoretical values and possible in-line problems. The WIP data can be broken down into part types at the equipment type. Another set of data to validate against is the equipment state performance data. This was already collected as input to the simulation.

4 BENEFITS

Automating the collection of factory floor data and integrating the data into simulation models has undoubtedly made model building and model validation of current factory scenarios much easier and faster. The development of this system has also provided valuable information that can be used to evaluate the performance of the current manufacturing plant and make improvements. Both the input data used for simulation and the output data used for validation are critical pieces of this evaluation. Figure 1 shows a high level orientation of an integrated and automated system with components that use the input and output data. Following the figure are discussions of the data each component utilizes along with a brief description of what it does.

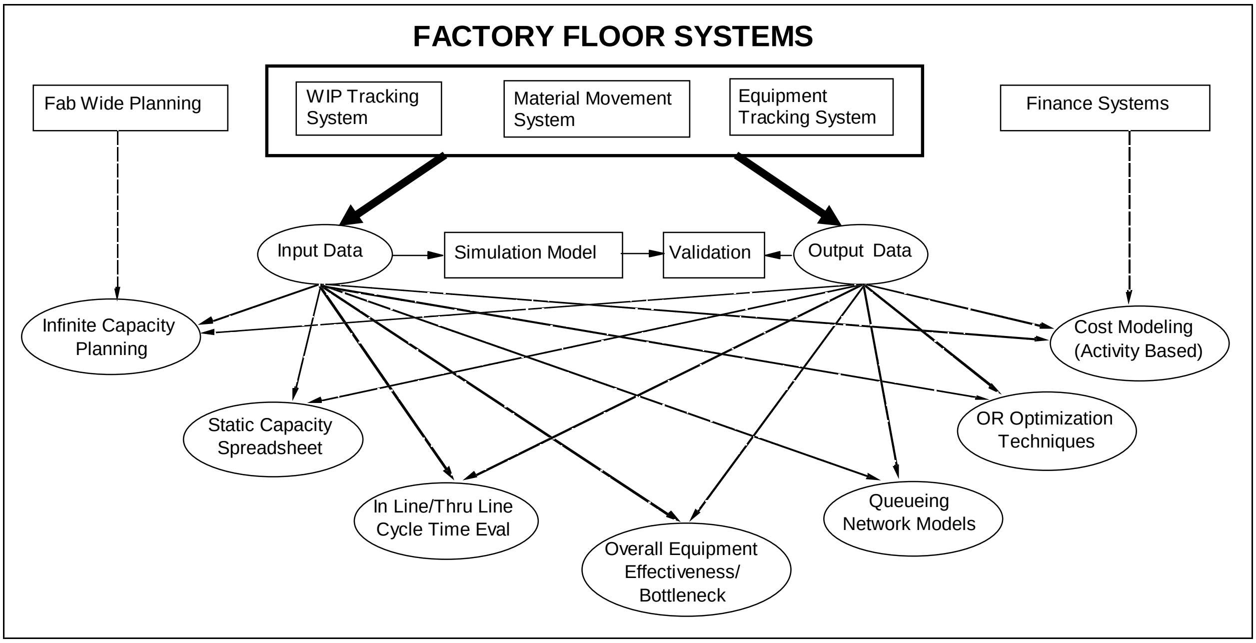

Figure 1: Factory Floor Systems

The first ancillary effect evolved from having process flows with theoretical processing at the recipe level for all active parts built on a daily basis. This enabled us to do some cycle time and WIP evaluation of all product that is currently in the line. One advantage to this is average semiconductor product cycle time can be typically 3-6 weeks. Having to wait for a lot to ship means that some of the steps making up the lot's performance occurred weeks ago. In line measurements, if trended or monitored frequently, can indicate problems more expeditiously and efficiently. The advantage from this is that cumulative in line times theoretical cycle time can be evaluated. This is done on a lot by lot basis to lots with poor cycle time performance. This is also done by product names to get an idea of current in-line cycle time performance by part. It is also used to trend the overall line performance with regard to cycle time and WIP.

Another benefit from the data is that we were able to establish an infinite capacity planning system. This system requires accurate process flows with theoretical processing time, historical recipe and equipment cycle time data, and the current status of all parts in the line along with required demands from the fab. The current status of the parts in the line comes from the WIP tracking system and the required demands comes from a fab wide planning database. The planning system essentially takes the current status of each part and forecasts it forward using historically weighted cycle time performance. This historically weighted formula can be adjusted however the user feels necessary. This forecast for every step of every lot is run multiple times in the day, and the output from it is used for two things.

The forecasted out of the line date for each lot is used along with the required demand data to establish a report that is used for factory planning. This report matches lots to the customer demands. The matching is a soft match that can change as line conditions and yields change. The tagging of lots to demands provides a report that helps identify lots that are or could potentially be late to customer demands. In addition to this, it also provides the lot ship information to the shipping department when a lot is complete.

This identifying of late lots even with this report can become complicated due to the number of lots in line. Because of this, the system will identify these lots automatically through a routine based on the forecasted out date and the customer due date. This information is fed back into the WIP tracking system and this is what drives the lot selection for dispatching at the tool.

Another purpose for the output is that all lot arrivals at each equipment type for the next twenty-four hours is reported. This gives the factory personnel the visibility to the quantity of product and the type of product that will be arriving at the equipment they are operating. This is used to make local decisions as to whether or not to pull inventory from upstream locations so as to keep bottleneck tools from running out of inventory to process. It can also be used with some capacity constraints to predict future bottlenecks. It also helps provide information to answer tool setup related issues.

The input and output data for the simulation can also be used to help develop an activity based cost model. The data needed for this is the historical equipment state performance, equipment cycle time data, current product flows with theoretical cycle time, and historical financial data. The financial data is compared to past equipment performance data for the same period. This comparison yields a cost per minute of utilized time on the equipment. This cost per utilized minute of time is then integrated with a capacity spreadsheet to help predict the wafer costs for any identified product mix. To make this activity based, the financial data must be broken down by its cost drivers at each step of processing completed by the equipment. In some cases the costs can be allocated to the equipment on a generally agreed upon percentage.

The cost model above utilizes another important benefit from the input and output data for simulation. This resultant benefit is a capacity spreadsheet. A simulation model from a semiconductor fab typically has an extremely large amount of data used as inputs. Often, one of the biggest problems with simulation is that if the simulation shows something different than what the customer thinks might happen, the customer becomes doubtful of the data used as input. Since the collection of the data is automated, manually checking to make sure there is not a problem with the automated programs requires reams of data. Neither the customer nor modeler wants to review all the data.

To solve this problem, a program was written that took inputs from the simulation like the active flows with theoretical processing time, equipment state changes, and equipment information. This information was summarized in a large static capacity spreadsheet. The spreadsheet was organized to the customer's specifications with common data being grouped together and summaries provided where applicable. The spreadsheet can be quickly opened and reviewed to help answer and resolve nagging data validation issues or unexpected results. Through the adding of equations to the spreadsheet, it evolved into a static capacity spreadsheet model. This tool becomes very useful for establishing starting points for future capacity analysis problems. It is also useful when the capacity question being asked does not require a discrete event simulation model.

The extracted factory data for simulation model validation can also be used to monitor factory performance trends. Equipment availability and utilization performance can be graphed with WIP and throughput to show performance problems. Adding to this the theoretical processing time, the Overall Equipment Effectiveness can be measured. Average equipment cycle time and the weighted theoretical processing can also help identify cycle time bottlenecks. The equipment performance can also be broken down by shifts to show other possible problems.

Other uses for the input and output data used to build and validate simulation include inputs and validation data for queuing models. Making sure that all modeling tools use the same data makes it much easier to assess the usefulness of the tool and also to validate the tool. Also, the data can be used for other Operations Research techniques such as linear programming. This has yet to be attempted in a global sense at MOS 12, but the data is there for later use.

5 SUMMARY

Simulation has provided MOS 12 with a method of modeling the manufacturing line for the purpose of measuring the line performance under different scenarios. The contribution simulation has made to this purpose is unquestioned. An important ancillary effect from the establishment of the infrastructure to automatically collect and integrate factory data into the simulation is that now there is a wealth of factory data that can be evaluated and combined with other types of data to add to the characterization of the manufacturing process. This extra benefit makes simulation even more worth the effort to maintain and execute.

However, the importance of having such data for a factory highlights the need for a factory data warehouse for factory performance and modeling data. The current method of data collection, while automated does not populate all data into a true database where key fields can be easily linked through SQL queries. A data warehouse project is currently under way at MOS 12. The extraction of data from the systems that was done in the past is very useful for creating the entity relationship diagrams that form the database. The direction for the future will be to complete this robust data warehouse so that better integration with the existing factory floor computer systems can be accomplished. With this, the true functionality of a data-mining tool can be integrated with reporting tools and modeling tools.

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