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SUPPORTING SEMICONDUCTOR MANUFACTURING SIMULATION TOOLS USING A STRUCTURED DATA MODEL

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ABSTRACT

This paper discusses a structured data modeling approach which is used to maintain and support two different simulation tools. The data model is stored in a relational database system which provides the links for each tool to access the data. One tool provides short interval production schedules for the semiconductor manufacturing operations at NCR and the other tool performs a wide variety of factory analyses on the same wafer fabrication plants. Powerful user interfaces were built on this system which enable the end users to run simulations of both experimental and actual situations. This environment has also facilitated the maintenance and continuing use of the data over a period of twenty months. In this paper we will review the use of the data model in linking manufacturing users to simulation tools, describe the tools currently in use at NCR and highlight the pros and cons of using multiple tools and a central database.

1 INTRODUCTION

The manufacturing of semiconductor devices is a complex process requiring a large array of equipment and human resources. A typical Application Specific Integrated Circuit (ASIC) requires over 200 operations and often visits the same machine several times throughout its route. The amount of data required to model such a complex process is tremendous. In addition to the routes and equipment mentioned above, there are processing times for each operation, setup times, labor requirements, and equipment failure and repair data.

We build models of the manufacturing process to answer questions posed by different levels of management and to improve the performance on the production floor. Because these questions come from a variety of levels and the response time requirements may range from minutes to months, a single modeling tool was not sufficient to meet all of our needs. By building several tools tailored to the end user requirements, yet driven off the same data model, we are better able to meet the needs of our manufacturing organization.

1.1 Wafer Fabrication Terminology

This section defines several terms used in describing semiconductor manufacturing operations (Baum and O'Donnell 1991). A **lot** is defined to be a collection of wafers which require identical processing steps. Lots are often grouped in a **batch** when required to efficiently load a piece of equipment. The **route** specifies which workstations to visit and the process plan to be used. A **workstation** is defined as a group of one or more identical, interchangeable machines that share the same reliability and throughput characteristics (Najmi and Stein 1990). An **operation** is a distinct processing step in which a task is performed at a workstation on a lot or batch of lots.

2 DATA MODELING

2.1 Database

We use relational databases to store the information needed to define our wafer fabrication operations at a level of detail required by the simulation applications. We have one database for each facility, Fort Collins and Colorado Springs, and these databases are virtually identical in structure. The database consists of base tables, application specific tables, and tables for results.

2.1.1 Base Tables

The base tables contain the core data describing the manufacturing facility and processes. These tables are used by both simulation applications and as references to build other tables. The three most important tables are: the workstations table, the route description table, and the operation description table.

The workstations table holds information about each of the machine groups in the fab. The number of identical machines in a group, the area of the fab the workstation is in and the labor group which runs the equipment are columns in this table. The route table describes every process in the fab by listing each operation and the sequence in which it must be performed. The table of operations then defines how long the step takes (for both labor and equipment) in terms of time per wafer and per batch. It also defines the batch size (number of wafers) for this operation and states the workstation which performs this task.

Other base tables in the database define additional elements of the fab. The areas table lists the subdivisions of the fab (Photolithography, Etch, Diffusion, Thin Films). The labor table defines the number of workers in each skill group for each shift; the shift times are defined in a separate table.

2.1.2 Application Specific Tables

The application specific tables are included in the database for the particular needs of the simulation applications. FabSmarts, the short interval simulation tool depends on a snapshot of the state of the lots in the fab at the start of the current shift. In contrast the long range SIMAN[1] model requires data on the mixture of processes running in the fab, the number of wafers started on a weekly basis, and the distribution of sizes of lots. Due to these different requirements there are more than 20 of these application specific tables in the database.

In addition to the WIP snapshot table, FabSmarts requires other data about the current shift that is being simulated. Shift start and end times, down equipment lists, and batches of lots due out of long furnace operations are all needed by the simulation. These tables and others are used by the INGRES/4GL[2] user interface program to FabSmarts which will be discussed later in this paper. Additional tables specific to the FabSmarts application define the dispatching decision rules. These tables allow for different rules to be set for each area of the fab, and separate production targets to be set for each workstation.

Several tables are used solely for the SIMAN capacity model. These include the tables of distributions for unscheduled machine failures, lot sizes, and product mix. In addition, three temporary tables are copies of the base tables for process times, workstations, and route sequences. It is these temporary tables which are edited through the user interface when different scenarios are modeled. Other tables include information on labor available in each fab area per shift and the number of wafer starts per week.

2.1.3 Output and Results Tables

One of the most powerful aspects of the database is the ability to create a varied selection of output reports based on the simulation results. The primary goal of both simulation tools is to communicate the results in the form of useful schedules and reports to the end users. Therefore we have created a number of tables that contain output data aggregated and post-processed in a variety of ways. These tables are then used by INGRES Report-Writer programs to generate the diverse collection of reports used at each fab.

2.3 Links to Shop Floor Control System

A substantial amount of the data in the base and application specific tables is derived directly from the Workstream[3] shop-floor control system. All of the route and lot data is extracted from Workstream and uploaded into the database on a routine basis. There are plans to pull equipment mean time between failures (MTBF) and mean time to repair (MTRR) data directly from the Resource Tracking (RTC) module of Workstream. Because this module is a relatively new installation in our fab, there is not yet enough historical data in this system.

2.3 Links to Sources of Other Data

The concept is to gather process step data or equipment recipes and work-force data directly from other sources. The data in these sources would be maintained by the organizations and people who are responsible for it (e.g. Process Engineering and Manufacturing Management). One of our planned projects is to build a database and tool set for the process engineers to update and maintain the operation time data.

3 TOOL SETS

3.1 Applications

3.1.1 FabSmarts: Short Interval Scheduling Tool

FabSmarts (Semiconductor Manufacturing Analytic Resource Target Scheduler for Fab) is a simulation tool written in Objective-C[4] and is based on the Berkeley Library of Objects for Control and Simulation (BLOCS)

(Gadre et al. 1990 and Glassey et al. 1989). It is used by both NCR wafer fabrication plants on every shift to generate schedules and targets for that shift. It runs a short interval deterministic simulation based on data from the Workstream WIP tracking systems, and on data entered by the key-users that is stored in the INGRES database. The simulation attempts to model all of the production events that will occur during the course of the coming shift. Every operation on every lot at every machine is explicitly represented. However, unexpected events such as random equipment failures are not modeled due to the fact that we can not predict such occurrences.

The primary use of the FabSmarts schedule is slightly different at the two fabs. In one fab the output is an extremely detailed schedule of every production event at the key workstations (an adjustable list of machines deemed to be mission critical; this list contains the bottleneck, near bottleneck, and most 'one of a kind' machines). This report is carried into the fab, posted at the equipment, and serves as a guideline for the operators in making their production decisions. At the other fab the schedule is aggregated by one level: the total number of wafers of each process type that were scheduled to run is given for each operation at the workstation. This report is also posted in the fab and the numbers are viewed as targets for the shift. At the end of the shift another report is generated which measures the actual performance achieved and compares it with the schedule. Large variances are then discussed in the daily production meetings, problems are exposed and recovery procedures are undertaken.

Operation of FabSmarts:

1) A snapshot of the WIP is taken automatically from Workstream, and the data is passed to the SPARCstation[5]. That data is loaded into the lot-status table in the database and other tables are filled with the snapshot date and time and the shift number and its start and end times.

2) An initial report of the lots sorted by area of the fab and processing step is generated for the Lead Production Operators (LPOs). This report helps them find lots in the staging areas (queues) and assists them with their manual data collection tasks.

3) The LPOs then input various data into the FabSmarts database tables using the FabSmarts user interface (see following section on user interfaces).

4) Upon the completion of the data entry, the user then selects the 'run' option. The simulator reads data from the database tables to initialize the objects and then runs a discrete-event simulation of the shift. The duration of the simulation depends on the length of the shift, but the total initialization and execution time is less than 10 minutes on a SUN SPARCstation.

5) Some simple reports are created directly by the simulation and are sent automatically to a printer. Another output data file containing the simulated production events is loaded into the database and is used to generate the complex reports specific for each fab management.

6) After printing the schedules, all the tables, reports and execution log files unique to the current shift and simulation run are saved to backup directories. This is done for historical purposes and for debugging and problem solving by us. On numerous occasions questions have been raised by fab management about the FabSmarts schedule; the data files saved in these directories have proved themselves extremely valuable.

One significant feature of the FabSmarts simulation is the sophisticated dispatching decision logic which has been implemented in the Objective-C objects. Versatility in the design of the FabSmarts code and database allow for different dispatch rules to be implemented in each area of the fab. For instance, the Etch area may use a rule that prioritizes lots based on which is the most late, while Diffusion and Thin Films may use the common FIFO rule. At the same time the Photo area may use a round-robin scheduling rule (Dayhoff and Atherton 1986) with a set target for the number of wafers at each layer to be processed. This round-robin rule was requested by one of the fab managers and was then further enhanced to allow a different target to be defined for each workstation in the fab. This was required to handle the different expectations and capabilities of different equipment sets.

All data needed to create a simulation run is read from the database tables using Embedded SQL in the Objective-C code. By design this means that there is only one executable version of the FabSmarts simulator to handle both fabs. All fab specific features are handled within the c-shell scripts which invoke other functions such as the INGRES/Report-Writer programs which create most of the output reports. This modularity of design has enabled us to make many changes to data, simulation code, and report programs on a weekly basis. The resulting flexibility is a key factor in FabSmarts meeting the changing requirements of management in our dynamic environment.

3.1.2 Factory Analysis Tool

A discrete event simulation model of an ASIC fab was developed using the SIMAN simulation language. The purpose of this model was to study the wafer fab capacity and answer questions concerning the impact of changes to the equipment set, labor resources and wafer starts rates. The results are measured in terms of cycle time, WIP turns, and wafers out of the fab. All model data such as equipment sets, product routes, process times, and equipment down times are stored in the central database. Depending on the desired changes, modeling a new scenario may be as simple as stepping through the menu driven user interface, or may require some manipulation to the database itself prior to using the user interface.

The base model is an "as is" model of the fab, containing the current equipment set, labor resources, product routes and process times. The user interface allows users to change the base equipment set, the labor resources, and the start rate and mix through a series of menus. More complex changes, such as adjustments to routes or operator-to-machine ratios require knowledge of the INGRES database. Once all the desired changes to the base model have been made, either directly to the database or through the interface, the user selects the "run" menu option. A SIMAN "experiment frame" is automatically generated using a combination of INGRES report writing capabilities and standard Unix functions.

Because the model is stochastic, multiple simulation runs are required. This feature is built into the model interface so the user is not required to have a detailed knowledge of statistics. A warm up period and multiple simulation runs are performed automatically. The output from the completed model runs are fed back into the database and a single output report is generated which can be viewed through the user interface.

The model has been used successfully to evaluate capital equipment purchases and to determine the maximum wafer starts levels which will allow us to meet cycle time goals. The model is also used to determine direct labor requirements for the wafer fab and to quantify the impact of labor on cycle time and WIP turns. The model also allows us to evaluate the impact of product mix on cycle time and throughput. The above mentioned issues can be modeled through manipulation of the database alone. Some more complex issues can be analyzed by making changes to the model code itself. These issues include dispatch decisions and batching logic.

One fab simulation study revealed a potential capacity issue with a robotic loader which serviced four furnace tubes. Simple spreadsheet analyses indicated that the loader had sufficient capacity. However, the dynamic simulation model revealed that without very tight scheduling of the furnace runs, the loader would become a bottleneck.

By keeping the data separate from the model, we were able to use this same model in a second fab. Some minimal changes to the model code were required to accommodate additional requests from users.

3.1.3 Other Tools

It is often desirable to have the ability to do a quick pass analysis. We have created a static spreadsheet capacity model to perform such analyses which is based on data contained in the database described above. All the processing times and tool listings come from the database. The spreadsheet also contains other information about wafer start rates and product mix on a six week rolling average. The spreadsheet allows for a very quick analysis of theoretical utilization of equipment for either the current wafer start rate or for a user input start rate and mix. Results from this type of analysis are often the impetus for more detailed simulation studies.

We have also been able to quickly evaluate other simulation tools, such as Mansim[6] (a simulator designed expressly for wafer fab simulation), using our real fab data. This task was simplified because the data is in relational form and can be downloaded into a file structure compatible with the package being evaluated.

3.2 Pros and Cons of Multiple Tools

One of the greatest advantages of running multiple models on the same data set is the ability to vigorously validate the data and the modeling methodologies. For example, some anomalies in the data did not show up in the FabSmarts scheduling simulations but became apparent in the longer running capacity model. Another advantage is that each model was designed for a specific purpose, i.e., short interval scheduling or longer term capacity modeling. Thus, the scheduling model contains a lot of detail not required by the capacity model and the capacity model tracks some measurements, such as average queues, that are not needed for scheduling.

The spreadsheet model also provides some advantages over the more complex simulation tools. The quick analysis that can be done with the spreadsheet model can provide a starting point for the discrete event simulation studies. For example, if the spreadsheet model indicates that an equipment resource will be over theoretical capacity, it is obvious that the simulation model will build an infinite queue at that resource. Knowing such things in advance can save the modeler from performing a lot of unnecessary simulation runs.

The main disadvantage is the need to support several tools. There is always some work involved in this, even if they do run off of the same data model. In addition, users must be trained on more than one tool and must understand how the tools are related.

4 USER INTERFACES

The database and its applications are implemented in INGRES on a SUN SPARCstation. We used many elements of the INGRES toolset: INGRES/ABF (Applications By Forms), INGRES/4GL (4th Generation Language), INGRES/RBF (Reports By Forms), and INGRES/Report-Writer. This allowed us to provide the same look and feel for the user interfaces to the different simulation applications. We invested some additional effort in standardizing the common menu items and keyboard commands to facilitate the ease of use.

4.1 FabSmarts User Interface

The interface to the common database provides a method for the user to define the state of the fab before the start of the simulation. It was designed to minimize the amount of time required for the user to input the necessary data, and maximize the accuracy of that data. The users of this tool are known as Lead Production Operators (LPOs); they perform supervisory tasks and manufacturing operations in the clean room. In general their knowledge of computers is satisfactory but not extensive.

One realm of data that the users enter specifies the state of the equipment in the fab during the current shift. All machines which are down at the start of the shift (not available for production) are identified and the predicted time at which each will return to a useful state is entered. For machines which have scheduled maintenance or other planned down time, the time of shutdown and time of completed repair is entered. Another function of the user interface defines unloading events at the end of extremely long process steps. Since some operations at the Diffusion furnaces are longer than an entire shift the FabSmarts simulation will not correctly model this situation without assistance. The user must specify the batches of lots involved in such an operation and the time they are due out.

To minimize data entry time and potential mistakes or confusion, on-line help for all menu options was built into the interface program. Also the structure of the data and flow of the program imitate the LPOs mental paradigm of the fab. Since the LPOs are responsible for certain functional areas of the fab (Diffusion, Etch, Photo, Thin Films), the data entry of equipment and lot status is divided by these areas. Also equipment is listed by its 'common' name rather than the engineering or official designation which might be unfamiliar to the operators. On each shift many pieces of equipment are down for short amounts of time by specification (cleans, checkouts, etch-rate monitors, etc.). A list of these planned down times is maintained in a table in the database. The elements of this table which apply to the current shift are then preloaded into the table of scheduled down time for the simulation. The only data entry now required is any changes and additions to the shutdown and repair times. The user is able to scroll rapidly through the list, and need only enter the military time of the event. In the majority of cases only the shutdown or repair time is needed, the other is correctly presumed to be the start or end of the shift respectively. Similar features assist the data entry for the other functions in the user interface.

4.2 SIMAN Factory Analysis Tool Interface

The SIMAN model interface allows the users to access data stored in the common database, to specify the changes required for the next scenario to be run, to run the model and to produce output reports. The interface is menu driven and designed to ease the task of modeling a variety of scenarios. The "base scenario" is a model of the fab as it stands today with the current equipment set, labor resources, start rates and mix.

To create a new modeling scenario the user chooses one or more of the following areas to modify in the base scenario: equipment set, labor, wafer starts and product mix. In the equipment set the number of machines of each type can be increased or decreased. For labor the user can modify the number of operators assigned to each labor area for each shift. Finally, the user can enter the number of wafer starts and the percent of wafers assigned to each product group, if different from the default in the base model.

A SIMAN "experiment frame" is required to run the scenario. This is created automatically by the interface when all modifications are complete and the user selects "go". This is accomplished through the use of INGRES Report Writer. A series of reports are generated from the data in the database, including the changes just input by the user, and these reports are concatenated to form the experiment frame. A c-shell script invokes the SIMAN commands to compile, link and run the model.

Upon completion of the designated number of model runs, the data contained in the standard SIMAN output reports are loaded back into the database. This allows the user to view the output through the menu driven interface. In addition, output reports are generated from this data using a format requested by the users. An advantage to this method is that the new output reports use terminology familiar to users, such as cycle time average and range in days, rather than the defaults in the standard SIMAN output.

5.0 CONCLUSIONS

The two simulation tools in use at NCR Microelectronics address different requirements for manufacturing and engineering management. The short interval simulation tool provides daily guidelines for the wafer fabrication operations and compares the actual performance against those targets. The capacity modeling tool answers questions concerning the impact of equipment, labor and process changes on the cycle time and fab output. It is our experience that the common database is an extremely useful device for supporting these simulation tools. We design and maintain one structure for all the manufacturing data needed to model the two wafer fabrication plants. Each tool is supplied with the formatted data it requires. In addition, the data in the database is available for the spreadsheet tool and for quick reference to answer questions from manufacturing and engineering. The relational database system and tools also provide a consistent environment for the user interfaces to the simulations and enable us to build a variety of output reports in response to the needs of our users.

1. SIMAN is a trademark of Systems Modeling Corporation.
2. INGRES/ABF, INGRES/4GL, INGRES/Report-Writer are trademarks of the Ingres Corporation.
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6. MANSIM is a trademark of TYECIN Systems Inc.

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