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OPTIMIZATION OF CYCLE TIME AND UTILIZATION IN SEMICONDUCTOR TEST MANUFACTURING USING SIMULATION BASED, ON-LINE, NEAR-REAL-TIME SCHEDULING SYSTEM

Appa Iyer Sivakumar

Gintic Institute of Manufacturing Technology
Nanyang Technological University
71 Nanyang Drive, 638075, SINGAPORE

ABSTRACT

A discrete event simulation based “on-line near-real-time” dynamic scheduling and optimization system has been conceptualized, designed, and developed to optimize cycle time and asset utilization in the complex manufacturing environment of semiconductor test manufacturing. Our approach includes the application of rules and optimization algorithm, using multiple variables as an integral part of discrete event simulation of the manufacturing operation and auto simulation model generation at a desired frequency. The system has been implemented at a semiconductor back-end site. The impact of the system includes the achievement of world class cycle time, improved machine utilization, reduction in the time that planners and manufacturing personnel spend on scheduling, and more predictable and highly repeatable manufacturing performance. In addition it enables managers and senior planners to carry out “what if” analysis to plan for future.

1 INTRODUCTION

Semiconductor manufacturers are facing stiff competition as more global capacity is being added. Intense competition has resulted in semiconductor manufacturers to initiate drives to improve their market responsiveness by reducing the cycle time whilst narrowing the cycle time distribution to achieve greater repeatability. The drive for higher utilization stems from capital intensive nature of the back-end constraint equipment.

Semiconductor back-end testing is probably one of the most complex manufacturing systems in terms of equipment, manufacturing routes, dependency and dependency relationship. This may be one of the reasons for the lack of advancement of simulation applications in semiconductor operations in this area (Moore 1997).

This paper describes concepts of a simulation-based on-line near-real time system that was designed, developed, and implemented to optimize cycle time and utilization by dynamically generating schedules and prediction reports for near term at a specified frequency.

Sections 2 and 3 of this paper look at the background followed by a brief description of our approach in section 4. The simulation, concepts, auto model building and optimization are detailed in sections 5, 6, 7 and 8. Sections 9 and 10 outline an application and results of the developed concepts.

The research was initiated with a vision to extend the use of simulation beyond the one off type of experiments. It has been suggested that all future production decisions will be made based on modeling and simulation (Goldman 1998). It was intended to apply the developed concepts to the semiconductor test operations with the ultimate objective of contributing to the achievement of world class manufacturing cycle time and high asset utilization by means of a highly responsive dynamic scheduling system.

As a first step a manufacturing system analysis has been carried out and it was established that the maximum impact on cycle time distribution and asset utilization would be realized by addressing the scheduling of constraint machines. The test operations are the constraint in back-end, which is the justification for focusing on test operations.

2 SEMICONDUCTOR BACK-END

Semiconductor or integrated circuit (IC) manufacturing consists of four distinct stages, namely the wafer fabrication, wafer probe or test, IC packaging and assembly, and IC burn-in and functional (electrical) test. The wafer fabrication and wafer testing are usually known as the front-end and the IC assembly and testing are known as the back-end. Figure 1 shows typical semiconductor back-end manufacturing flow.

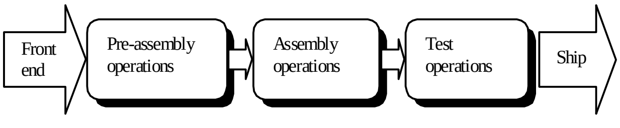

Figure 1: Simplified Semiconductor Back-end Flow

The back-end has three main facilities, namely the pre-assembly, assembly, and test operations. The focus of this paper is test operations.

Test operations are carried out in different types of testers such as analog, digital or mixed signals, depending on the functionality of the components and often results in a grading process known as binning. After the first series of tests, the components may be transferred for the burn-in process, followed by a series of post burn-in tests. Test facilities are generally capital intensive and usually they are the constraint operations in back end.

In general there is a high variety of products and a typical back end facility may handle in excess of 2000 products, each requiring different testing and burn-in specifications. The number of process flows or routings are substantially high. High product mix leads to variations of routing flows and routing time. Complex product-to-tester relationships usually exists according to device and package specifications where device describes the electrical specifications whilst the package specification includes physical dimensions and lead count.

Cycle time of the assembly operation in a typical back-end usually falls in the range of 3-6 days. Typical test operation cycle time is in the region of 1.5 to 15 days. This wider range is primarily due to larger variations in process flows and complicated and varying test conditions in the testing areas.

In simple terms the challenge faced in the test operations may be described as follows: Suppose that there are over 150 testing machines and about 800 lots waiting to be tested at any one time. The lots cover over 600 unique part numbers and require varying test setups. Each lot has aged to a different level, has a different due date & time, and requires varying setups on the testing machines for each test step. There are a large number of non-constant constraints for the machine-lot combination, caused by a multitude of hardware dependencies. The setup matrix shows that there exist over 50,000 different permutations and combinations to machine setups. The real time data shows that machines are in a different status. Few of the testing machines scheduled previously are not working now whilst few of these that were not working according to the previous schedule are now running.

The above scenario, common in typical assembly and test operations, posses an enormous challenge to operating personnel who wish to decide which setup to do next and which lot to load on a testing machine next. In practice, however, there are simple manual procedures and rules used in the back-end such as family grouping of testing machines and earliest date code or first-in-first-out (FIFO) rules which govern the lot selection. However, such a manual selection can hardly be one that gives an optimum utilization for the machines whilst achieving narrow cycle time distribution (Lu, Ramaswamy, and Kumar, 1994).

3 SIMULATION AND SCHEDULING

Simulation has become a popular technique for developing production schedules and dispatch lists in a manufacturing environment (Morito and Lee 1997), (Mazziotti and Horne 1997). Simulation offers the advantage of developing a feasible and accurate schedule in shorter computation times compared to some of the other techniques (Mazziotti and Horne 1997), (Kiran 1998).

Lu, Ramaswamy and Kumar have addressed cycle time in which scheduling policies are defined to reduce mean and variance of cycle time in semiconductor manufacturing (Lu, Ramaswamy and Kumar 1994). Application of ManSim simulation tool from former Tyecin Inc. to carryout production control in front-end operations of semiconductor has been outlined by Thiel (Thiel, Schulz and Gmilkowsky 1998).

The real challenge is in the application of online simulation (Davis 1998) in complex manufacturing and other real life applications. In the application of online simulation, it has been suggested that near time transient performance of a system as it evolves from its current state is a critical element (Davis, Chen and Brook 1998).

However it is suggested that the online simulation is in its infancy but shows great promise for the future (Banks 1998). Operational simulation is another terminology used by Anderson and Olsson. (1998) and it is stated that it covers short term planning and control, using highly detailed models that are integrated to other information systems. An application of real time simulation logistics has been reported by Ruiz-Torres and Nakatani in which the prototype system is used for due date assignment (Ruiz-Torres and Nakatani 1998). The problems of initializing on-line simulation have been reported by (Gonzalez and Davis 1998). They have developed a software for controlling and simulating an FMS system.

Off line analysis of semiconductor front end has been widely reported for example, (Rose 1998), (Grewal Bruska, Wulf and Robinson 1998), and (Domaschke Brown, Robinson and Leibl 1998)

The application of simulation based scheduling using real time dispatch (RTD™) tool from AutoSimulation inc. has been reported by Rippenhagen (Rippenhagen and Krishnaswamy 1998). The application was at a wafer fab of AMD Semiconductor manufacturing. The other application at Sony semiconductor front end is reported by Watt (Watt 1998).

Very little, if any, is reported in literature relating to online simulation of semiconductor back-end test operations. In one such work a Pareto boundary is defined to obtain optimal solution to multi-objective scheduling of IC sort and test operation (Yang and Chang 1998). Since scheduling and optimization problems are multi-objective and computationally intensive, Yang and Chang have used a Lagrangian relaxation method, in which the constraints that are difficult to solve are relaxed and absorbed into the objective function. The work, however, is not based on on-line simulation but a two-stage approach.

4 OUR APPROACH

Our approach involves the generation of schedules in a typical manufacturing application using a deterministic on-line simulation of the facility. Simulation is initiated from the real time status of the facility and environment. All random events such as machine breakdowns and machine assists are not included in such a run since "scheduling" a failure is unlikely to serve a useful purpose. Random variations in input data such as yield are also replaced by defined values, in most cases with mean values. The simulation run with defined rules and policies then gives a repeatable performance and desired schedule that should be followed in the test operations in near term.

A simulation based scheduling system usually requires a two-stage approach (Yang and Chang 1998). Offline experiments would be carried out in the first stage with different scheduling rules to determine a condition that achieve the desired performance of the manufacturing system. This set of dispatching rules will then be used in operations to generate the schedules. As the circumstances change, the analyst need to rebuild the model and re-run experiments to determine the right set of rules for operation. This requires a high maintenance effort for simulation based scheduling systems.

We followed an approach of auto model generation and integrating the management policies, rules and algorithms into the system, translated as parameters. This approach resulted in a considerable reduction in the maintenance effort. The characteristics of the schedule can therefore be tuned through these parameters to modify the behavior of the dispatching logic. The details of the dispatching logic and controlling parameters are outlined in section 8. Auto model generation ensures a near-real-time reflection of the manufacturing system.

Our model has focussed on modeling the testers together with the required secondary resources such as handlers, and hardware. Down stream operational work-in-process level is included to provide early warning of problems in down stream non-constraint machines. No operators have been modeled, as they are not considered as constraint on the system performance of highly capital intensive testing machines. However if they become a constraint, it will be handled as constraint resources by the system in a similar manner.

5 SIMULATION TOOL

TestSim/X™ (base simulation engine) from former Tyecin Inc. was selected based on an evaluation. Primary criterion includes its specific constructs for modeling of semiconductor assembly and test environment and speed of execution among others. The tool provides a data driven approach for simulation model building and 'user access' feature for customization. Automatic model generation programs, described in section 7, read the data from various files and databases and create the files in formats required by the tool to build the model. The model is then executed using the customized dispatching logic developed (section 8) and the simulation events recorded in the lot and machine detail databases. These databases are then used by interface programs (section 7) to create the lot and testing machine schedules that can be communicated through the shop floor system terminals to the operators on the test floor. The reports and schedules generated by the interface can be accessible to a large number of managers through, for example, a client-server user interface.

5.1 Resource Modeling

The simulation tool provides special constructs to model tester and handler and these features have been used. Four different types of constraint hardware are modeled and these are 'loadboards', 'dutboards', handler conversion kits, and a device family specific hardware. Each of these hardware groups has a large variety of hardware types (hardware part numbers) and different quantity of each of these hardware part numbers may be available at any one time.

5.2 Process Modeling

Description of products and their process steps is required to model the processes. The process steps basically define how the resources are used to test the product. The selected simulation tool enables the devices to be modeled as products and linked to processes. However, in a typical back-end operation the same devices may be processed using different steps due to the fact that one device corresponds to multiple products. In addition a proportion of products have alternative operation routes.

Normally, the resources required for an operation are defined in the process step description by filling in the fields for workstation for the step and process time. However, for test operations the resource requirements are specified differently due to complex resource requirements. The testing steps require multiple resources including tester, handler, and several types of hardware. In reality there are more resources required, such as operator, etc. but they have not been included in the model, as they were not seen as critical constraints.

A testing step can be carried out using alternate combinations of the above resources. For example, a test step may be carried out using the same tester and handler but a different 'loadboard', or it may be carried out using a different tester, handler, and 'loadboard'. Process time for these alternatives can be different, as it is made up of testing time and indexing time.

In the selected simulation tool, the information is termed as tester hardware dependencies for a product and can be defined for each test step. Alternate resource combinations can be specified as alternative tester hardware dependency combinations.

5.3 Machine Setups

A number of major factors have been taken into account for modeling the setups in the model including handler change, handler conversion, hardware change, temperature change, and test program change. A setup is considered based on the existing setup and the new setup to determine the total time required for setups.

Setups can be defined in several different ways in the simulation tool. In our model, setup times are defined in two components. One component of set up time is based on product type while other component is defined based on 'spec codes'. The 'spec codes' in the simulation tool specifies the setup parameters such as device, package, lead count, test temperature and so on. The product type set up is fixed while the spec code component is based on sequence dependency. The setup time is the sum of times of applicable components.

5.4 Dispatch Rules

Dispatching sequence in a factory are controlled by rules (policies) that determine the sequence of operations on different resources. Dispatching rules determine which lot will be loaded next on an available machine from among the lots waiting in queue to be processed. Test lot queue is modeled at the tester group level and is scheduled when a test equipment in the group becomes available. The equipment may become available after finishing a current testing operation or after completing a planned event such as preventive maintenance.

Different rules govern the dispatch decisions in the simulation tool. The features of 'setup rules' and 'loading rules' are found not suitable to realistically model the actual back-end practice. As a result we use the feature known as the 'user access' in TestSim/X™. This customization feature enables external prioritization and optimization of the lots and allows the simulation to select the highest priority lot using 'Dispatch rules'.

5.5 Unavailable Time

The time available for running the machines is defined by the shifts and break schedules. This is more critical when operators are critical constraints. IC testing is primarily an automatic operation and usually a continuous operation is used in most operations. The tool features the definition of shift and calendar.

The preventive maintenance (PM) feature of the simulation tool allows defining the frequency and duration of PM events that can be executed many times over a long simulation run. Since the intent is to simulate for near term, this feature was not found appropriate in developing our concept.

The feature appeared more suitable has been 'engineering shutdowns', which allows defining specific times with duration for tester unavailability. This feature is used for modeling preventive maintenance events and all other engineering shutdowns that are usually defined in the factory systems and databases.

Testers or individual tester heads can be unavailable for testing at any given time for various reasons in addition to the PM and engineering shutdown events. Often the factory systems may not have defined these through the appropriate factory systems. If the current status of a tester head accessed using real time shop floor data found it to be unavailable for testing, then it is reflected in the model through the use of dummy lots.

Dummy lots are created for a product that matches the last known setup on the tester head with a quantity that will make the head busy, and thus unavailable, for a predefined period. Dummy lots also offer the flexibility of making only one head of a multiple headed tester unavailable, something that can not be done by PM or shutdown features of the tool. These are some of the limitations of most simulation tools relating to on-line modeling of semiconductor back-end.

5.6 Product Inventory Definition

The status of current work-in-process inventory is defined by providing information on all the entities (lots) that are in their test route. For each lot, attributes such as the product, quantity, priority, current operation, route and the cycle time to-date and so on can be defined. The current operation and route are used to position the lot at correct processing step.

5.7 Operations In Progress Definition

The lots that are undergoing testing at the start of simulation (i.e., at the time of data collection by shop floor system) are also defined as part of the work-in-process inventory. For each entity that is part way through its testing operation, additional attributes such as, the current workstation, the current secondary equipment in use, and the time that has already elapsed since the beginning of the operation are also defined. In simulating the production process, the lots will complete their remaining number of pieces to be tested and then proceed on to selecting the next lot. This feature is one of the most critical features of on-line simulation (Davis 1998).

6 OVERALL CONCEPT AND SCOPE

The system concept is shown in Figure 2. A three-tier client server architecture is used. The system has a data tier, the client tier and the system tier. The data tier provides almost the entire data from the manufacturing environment to generate fresh simulation model in every run.

Entire data required by the simulation model can be owned and maintained by factory systems and databases. The client tier is external to the system and it is felt that the more appropriate alternative is for this tier to be an integral part of the factory reporting system where all reports and schedules can be made available to appropriate clients to aid their functions. The additional features that a factory may require are a user interface (GUI) for maintaining non system data (e.g., cooling time of a handler xyz from temperature t1 to t2) and "what-if" runs. The system layer consists of the model generator, report generator and the simulation engine integrated with specific and customized schedule optimizer. This layer is probably unique to each plant.

7 AUTOMATIC MODEL GENERATION

The simulation model is dynamically generated based on near-real-time data collected from the factory systems and shop floor. Thus the simulation model in this system is a live one as opposed to conventional static models. It provides the scheduler an updated view of the entire environment and therefore ensures good integrity between the schedule and the shop floor activities. Figure 3 shows the detail of the concept design. This concept is developed using six sub modules.

(i) Interface classes to factory input database,
(ii) Interface classes to TestSim/X™ database,
(iii) Interface classes to internal database,
(iv) Model generator,
(v) Schedules and reports generator, and
(vi) System integrator and controller.

Sub-modules 'interface classes to factory input database' and 'interface classes to database' are a list of software classes used for reading and/or writing data files in various databases. The software extracts key information from the data files provided by the factory database, and translates it into a simulation model, which reflects the current shop floor state, known schedule events, and the entire simulation environment. The information includes the number and types of resources (tester, handler etc), current status of each resource, list of entities (WIP lots with attributes such as status and location), and a number of other data used for the optimization and scheduling algorithm. The programs in sub-modules 'model generator' and 'schedules and reports generator' use these classes. The sub-module 'system integrator and controller' contains shell scripts for integrating and controlling the various programs.

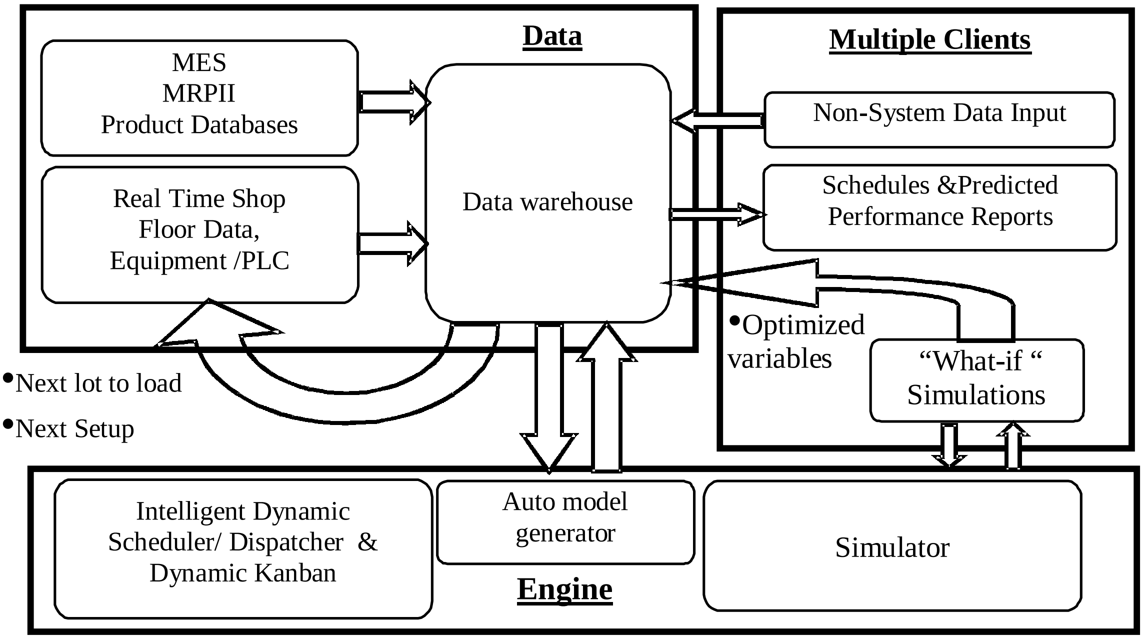

Figure 2: The System Concept.

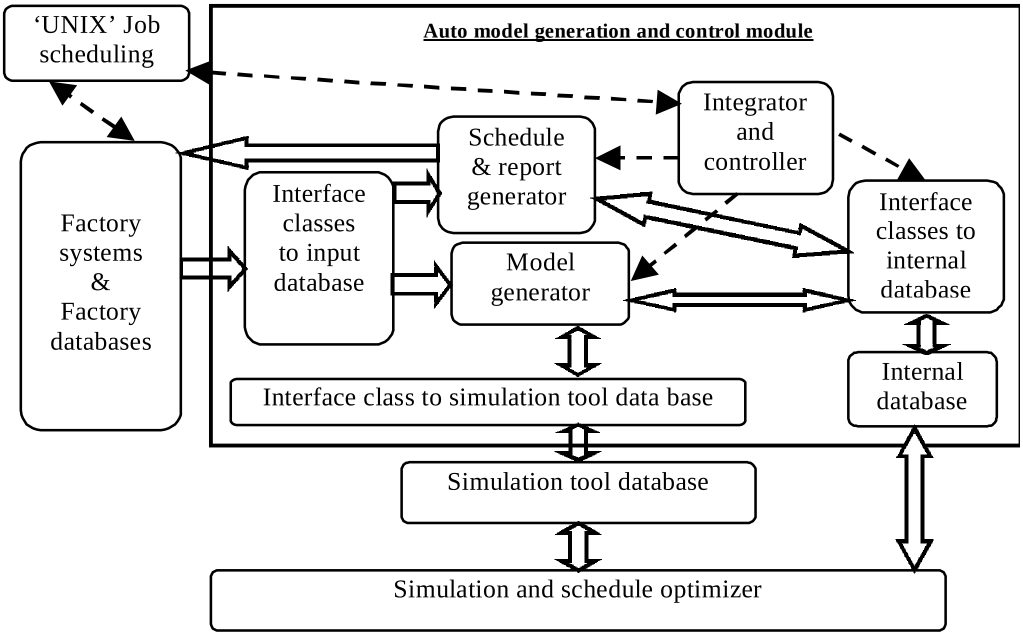

Figure 3: Auto Model Generator Concept

The interface system is designed using object-oriented methodology with the aid of a commercial design tool named Rational Rose™. All programs are written in the C++ language. Shell scripts are written to set the environment for system execution and to integrate the system interfaces with simulation and scheduling.

There are nine steps in constructing the TestSim/X™ model using data extracted from a factory database and systems. Step 0 uses the only static data while all others can be updated from factory systems at every simulation run.

Step 0: Copy Static Files
Initialization of static files such as such as simulation horizon, which are independent of online data.
Step 1: Create model of tester groups & testers using client specific tester data
Step 2: Create model of handler groups & handlers using client specific handler data
Step 3: Create product-equipment eligibility matrix
Step 4: Create model of current hardware availability
Step 5: Create model of products & processes (routes)
Step 6: Compute setup time requirements of all possible permutations and combinations of setups.
Step 7: Create model of tester PM and other unavailable time
Step 8: Create model of current entities (inventory & production lots) and resource based on current status.

At the end of these 9 steps we have an online model of the plant at its nearest state to real time. This status is "near-real-time".

The process continues with the simulation of the generated model of the plant. At the end of the simulation the simulation events are recorded in the lot and machine detail databases of the simulation tool. Customized schedules (dispatch lists, handler schedules etc), cycle time reports, utilization reports and custom reports specific for an application can be generated by the schedule and report generation module. These can be mapped into a factory database to distribute to multiple clients and testers.

8 OPTIMIZATION

The core of the development is the customization of the simulation engine to implement advanced scheduling logic and scheduling algorithms to optimize cycle time, delivery, and utilization. We used the C programming language for the development of this core part of the dynamic scheduling system. These programs have been designed, built, tested and integrated with the Simulation engine using the function 'user access' of TestSim/X™ in such a manner to take almost total control of the lot dispatching decisions inside the simulation. Each time an equipment becomes available in the simulated time (i.e. future time) the programs perform the scheduling optimization by choosing the most suitable lot to load on to the equipment at that specific time in future. The programs use a very large number of control variables to optimize, of which 39 are accessible and modifiable by the user who could be an analyst, manager, or senior planner. The optimization algorithm makes use of the weighting factors assigned by the user on the conflicting criteria of cycle time, utilization and delivery. The optimal selection of lots for each dispatching decision takes into consideration of all constrained resources that are required by the equipment. The dynamic status of the down stream WIP status is also considered in the scheduling decision (Mazziotti and Horne 1997).

Although optimization is the goal, we used heuristics together with Pareto optimization (Yang and Chang 1998), and as a result the generated schedules are not guaranteed to be optimal, but consistent, good, and controllable. The ability to take control of the lot scheduling in simulated time is the key characteristic of the system. Searching and generating the absolute optimum schedule at a point in time is not practical in our application.

The coding makes use of the dispatch control in the simulation software. However there are critical lot dispatching decisions where the external control is not enabled in the simulation tool and can be a limiting factor.

9 EXECUTION

Conventional users execute a TestSim/X^{TM} model through the interactive interface using the “Run” button. Our concept uses ‘batch run’ so that model could be triggered by external systems. The developed concept and system could be executed in three different modes: production mode, “what-if” mode, and variable optimization mode. In ‘production mode’ the system is triggered by an external system or an event and generates a fresh model, simulates and optimizes the schedule as frequently as needed by the client system.

In “what-if” mode a client triggers the system. This mode starts by copying the latest live model and enables the client to make changes in selected parameters. At the end of such a run a complete set of reports is generated for the client to compare results with that of an alternate set of parameters.

In variable optimization mode, an advanced user creates multiple copies of the parameter file and makes carefully selected changes in each parameter file. The variable optimization mode starts by copying the latest live model and simulates each set of the parameter file one by one over a longer period. Summary reports of each run is generated and written into a file for interpretation by an analyst. This mode can also be used to carry out other types of analysis such as Design of Experiments (DOE).

10 APPLICATION

The concepts resulting from the research and development have been designed in detail and implemented at the National Semiconductor (Singapore) site and are in use. National Semiconductor (NS) is one of the major manufacturers of semiconductors in Singapore. Established during the early seventies, NS has progressively expanded and currently manufactures over 275 million IC’s per year with a turnover of over US $1.5 billion. The varieties include PC products, telecommunication, ASIC’s, military, aerospace, and many other types of IC’s for local as well as overseas markets.

The system implemented at NS dynamically generates schedules and reports for the testers at a specified frequency, 24 hours a day, throughout the year. Over 200 shop floor operation staff rely on the dynamic lot selection decision generated by the system every shift. In addition 50 staff make daily use of the reports and schedules that are dynamically generated by the implemented system. The system, implemented on a SUN Ultra workstation under UNIX Operating system, takes about 7 minutes to generate a near term schedule. Of the order of 1500 scheduling decisions are made in each scheduling run and each scheduling decision may consider in excess of 2000 alternatives to choose the optimum.

The NS internal systems provide, at a desired frequency, status on current work-in-process inventory and exact location of each WIP lot, the process flow and the required primary and secondary hardware for the dynamic scheduling and optimization system.

Equipment and hardware data is extracted from the Resource Tracking System. The extracted data include the status and availability of testers, test handlers, and a variety of hardware required by the testers. The data are also based on new equipment or hardware introduced, items removed for preventive maintenance, and so on.

A Client-Server application has been implemented by NS that enables user-friendly manual data inputs, system setups and optimization parameters of the dynamic scheduling and optimization system. This application enables easy access to the reports generated by the schedule and encompasses other complimentary manufacturing reports needed by the operational staff. The system at NS is automatically triggered by other systems across the different applications so that no manual triggering is required for each scheduling run.

A number of other projects were initiated at the NS Singapore site that were crucial to the success of the overall project. One of the key aspects of the success is the development and implementation of a real-time shop-floor information system by NS that provides machine status data and current setup data to the dynamic scheduling system. This system also enables on line distribution of dynamic schedule results to each testing machine. The system has been networked to 150 testing machines of different makes.

The displayed information includes details of the next lot to load, lot location and product related information such as the required hardware, location of test programs etc. The information displayed is a networked link between the on-line near real time dynamic scheduling system and all the operators in the manufacturing area.

11 RESULTS

NS has realized tangible and intangible benefits. Intangible benefits include reduction of cycle time distribution by 3.5 X (theoretical cycle time) whilst achieving a high cycle time repeatability, highly accurate response to customer on order completion time, and rapid and accurate capability of “what if” analysis.

Tangible savings include a capital avoidance (one time) of US$ 5,000,000, reduced daily management time of 12Man-hrs/day, and increased tester utilization.

12 FURTHER RESEARCH

The major area of research identified is the development of simulation tools that are capable of online simulation of semiconductor environment. Such development must consider the need for customized scheduling, on-line integration, and capability of applying rules and optimization as an integral part of the simulation. Author currently undertakes this research effort. The objective is to realize an effective object-oriented simulation tool, capable of online simulation of semiconductor back-end.

13 CONCLUSION

This paper presented the concepts, development and application of an on-line near-real-time simulation and schedule optimization of semiconductor test manufacturing. This paper showed that baseline capabilities exist in certain manufacturing environments so as to implement on-line simulation. The application reported in this paper showed that significant benefits can be achieved in terms of cycle time distribution, utilization, and delivery performance. The concepts and system demonstrated advancements particularly in the following aspects:

- Near-real time integration of manufacturing IT systems including shop floor interfaces, manufacturing databases, and engineering databases with the scheduling engine.
- Dynamic creation of the simulation model at a specified frequency, eliminating the need for highly trained specialists for maintenance.
- Fully automated system running 24 hours a day only requiring intervention on a rare ‘need to do’ basis.
- Customized scheduling and optimization algorithms integrated with discrete event simulation that take into account a variety of factors.

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AUTHOR BIOGRAPHY

APPA IYER SIVAKUMAR is a Senior Research Fellow at Gintic Institute of Manufacturing Technology, Singapore. His research interests are in the area of simulation based optimization of manufacturing performance, and supply chain, and dynamic schedule optimization. He has many years of industrial and research experience in the UK prior to joining Gintic in 1993. He held various management positions including technical manager and project manager for nine years at Lucas Systems and Engineering and Lucas Automotive, UK. During this period he was responsible for manufacturing re-engineering projects and involved in the introduction of IT systems. He has also worked as an internal consultant to Lucas sites in manufacturing re-engineering, and IT applications. He received a Bachelors of Engineering from University of Bradford, UK and a PhD in Manufacturing Systems Engineering from University of Bradford, UK. Sivakumar has made several contributions at international conferences and journals. He has been the technical chair and co-edited the proceedings of the 3rd and 4th International Conference on Computer Integrated Manufacturing (ICCIM ’95 and ICCIM’97), Singapore.