Dynamic Simulator for WIP Analysis in Semiconductor Manufacturing

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_ Manufacturing Control and Execution _ Oral Presentation

Summary: We present a FAB Simulator (FS) and Capacity Planner (CP) that permits the operational planner to introduce new product into an existing production mix with confidence as to the customer delivery dates and FAB Capacity. This paper describes the implementation of these two dynamic tools in a semiconductor FAB in Arizona. These tools assist the operational planner with the planning of the daily production mix. This FAB produces 100's of different bipolar devices using 36 process flows. The key to success in calculating present and future production goals is real time operational level tracking. Real time tracked data includes data gathered from the Manufacturing Execution System (MES) for each product's work-in-process (WIP), process flow routing, and data gathered from the equipment utilization and emergency maintenance databases. This key information is fed through a GUI linked (Fig. 1.) to the CP, which in turn controls the stochastic dynamic simulation model of the FS. These links provide the operational planner with dynamic production data in real time and simulated time for decision-making. The CP and FS are running in parallel and are linked directly with the FAB's MES maintaining current production data.

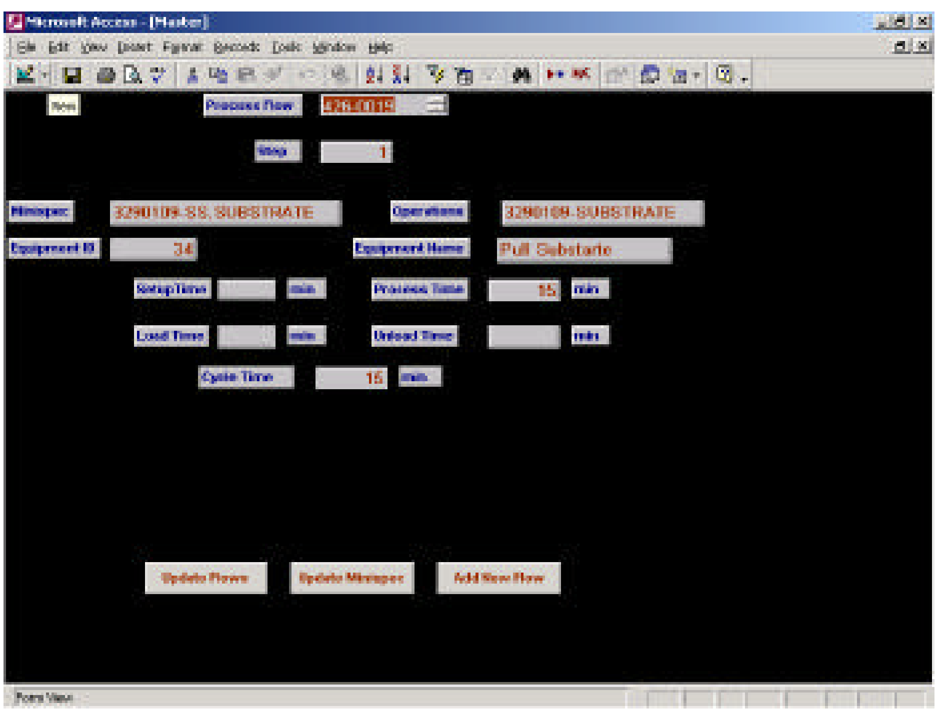


Figure 1. GUI – from MES to CP and FS

Starts mix [1] = the mix of products released in the FAB at a given time interval.
Production mix[2] = mix of products in the FAB at a given point in time.
Global approach[3] = evaluation of a bottleneck using all factory control variables.
Local approach[4] = evaluation of a bottleneck using local control variables.

Introduction: Semiconductor manufacturing planning and control to reduce cycle time (CT) and WIP while maintaining optimal utilization of expensive resources for a given production mix[2] is a top priority in "World Class" semiconductor manufacturing. Operational planners schedule starts and production mix[2] of product devices for semiconductor fabrication facilities (FABs). One of their top priorities, is to know how many, at what release rate and when to release new devices into the FAB (starts mix[1]). Another priority is to know what product mix is most effective in maintaining a balanced line with existing WIP, which allows confidence in customer delivery dates (production mix[2]).

<u>Capacity Planner Defined (a snapshot in time)</u>

A capacity planner is a system usually developed in Excel, where mathematical formulas determine through elaborate calculations, the WIP, CT, machine utilizations, and

FAB capacity at any moment in time. Determining the capacity instantaneously given the inputs. If the inputs change we can get a new snapshot or capacity of the factory.

Fab Simulation Defined (a movie)
A FAB simulation on the other hand has all the same inputs as a CP. However, they are dynamic and the model outputs are also dynamic. The result is a simulation model of the FAB that has been validated and linked to the MES database to predict or calculate dynamically WIP, CT, machine utilization and FAB Capacity based on current data being received from the live links. An analogy of a FS is a movie, determining the capacity dynamically given live dynamic inputs. If the inputs change, the FS is automatically recalculated to obtain the current capacity of the factory.

Table 1

	Can the CP or FS?	*Capacity Planner (CP)* *Theoretical times**	*FAB Simulator (FS)* *Real World Times***
1.	*Determine bottlenecks in the factory*	*Yes*	*Yes*
2.	*Determine how hot lots will affect delivery dates of all other products*	*No*	*Yes*
3.	*Predict bottlenecks based on orders and current work in process*	*Yes*	*Yes*
4.	*Prove bottleneck does not shift from one area of the factory to another when new equipment is added.*	*No*	*Yes*
5.	*Calculate Equipment Utilization*	*Yes*	*Yes*
6.	*Calculate ship dates of each product with 95% accuracy*	*No*	*Yes*

* Theoretical times = the amount of actual time a product would be manufactured if there was no wait time for any machine, i.e., the summation of the Setup, Load, Process, Unload and Travel time at each step in the device process flow (assumes no competition for equipment between products and no queue wait time).
** Real World Times = the amount of time a product is manufactured that takes into account wait time for a machine given a certain product mix, i.e., the summation of the Queue Wait Time + Setup, Load, Process, Unload and Travel time at each step in the device process flow (assumes there is competition for equipment between products and Queue Wait Time)

The FS also has the advantage to be run with projected orders (projected starts) using historical MTTF and MTTR data from the MES database to simulate offline manufacturing of a given WIP (*production mix*[2]) to determine capacity and assist the planner in predicting WIP, CT, Machine Utilization, and FAB capacity for future scheduling.

The FS is used more as a proactive tool to help production planners and managers to accurately estimate their delivery dates based on a production mix. They also can use a FS to clearly determine the capabilities of a FAB (capacity) for a given production mix.

Each of these tools have their place in semiconductor manufacturing. Table 1 demonstrates the requirements of semiconductor planners and operation managers when trying to manage production on the factory floor. Here we are asking that if the CP or FS can help the production planners answer these everyday management questions. What is important to note is the differences between the FS and CP. The FS is more effective than the CP because it can answer all 6 questions or requirements listed below.

The CP however cannot determine how hot lots will affect delivery dates of all other products in the production mix. It cannot prove a bottleneck does not or will not shift from one area to another area of the factory when new equipment is added nor can it calculate ship dates of each product with 95% confidence.

So the question arises why don't we just make a FS instead of a CP. The main reason is cost of data collection and software. Most production planners have a customized CP model to calculate within acceptable ranges the ship dates and can estimate how hot lots and bottlenecks will shift in the factory based on experience and trial and error. The CP is not as expensive as a FS using simulation software and live data collection but as demonstrated above has limitations.

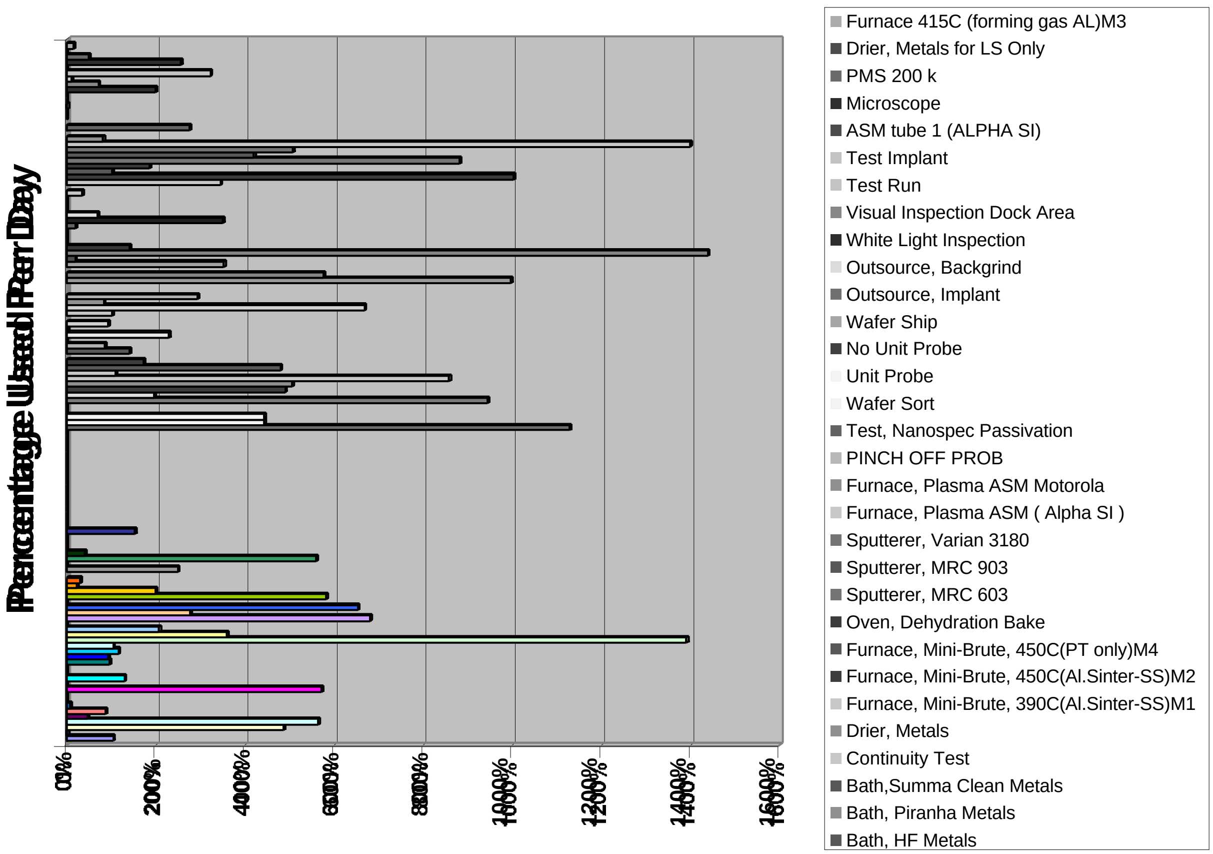
To prepare a FS you need the same types of information that a CP requires but they must be linked live to the MES database required to run the FS live. Once this is done there can be two FSs one run offline (a movie in fast forward) and one running live (live movie).

The offline FS now becomes a proactive scheduling tool and the live FS becomes the measuring and tracking simulation tool.

The CP and FS are dynamically linked, using the GUI in Figure 1., to the manufacturing execution system

(MES) and the emergency maintenance database giving the production planner real time control (Fig. 1.) New product orders (*starts mix*[1]) are entered by device number into the CP. The devices are sorted for production and merged with existing products (*production mix*[2]) or instantaneous WIP in the FAB.

Figure 2. Top 30 Machines Utilization Chart



The objective of the CP and the FS is to allow the operations planner to play "what-if" scenarios while introducing new products (*starts mix* [1]) into the existing production mix[2] to determine the most efficient production and customer delivery schedule. This is done by temporarily taking the CP and FS offline to introduce the new products by trying the "What-If" scenarios.

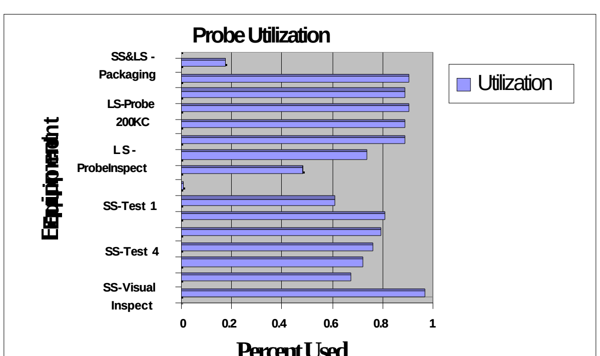


Figure 3. Probe

By running the FS offline, the planner can determine potential new bottlenecks caused by the addition of new products. The integrated FS with the CP present dynamic graphs of machine utilization's (Fig. 2.) for each of the machine groups using

historical maintenance data from the MES. Once the planner is satisfied with the product mix and has observed the bottlenecks offline, he then can schedule production and his maintenance crews. Once the starts are committed, the FS and CP are placed on line (live) with the FAB MES and each section manager can observe the dynamics of the machines under their control in real time during factory operation, e.g. the Probe Section (Fig. 3.).

The FS includes control variables such as; the production mix, the production flows, the production recipes, setup times, load times, processing times, unload times, the equipment maintenance database, and labor. These essential control variables are selected to achieve production optimality within time constraints determined by the variability on the factory floor such as emergency maintenance. A global approach [3], from the entry of a raw wafer through shipping the completed product, is required to incorporate the complexities involved in scheduling and releases policies for multiple product re-entrant manufacturing. Delivery schedules can be predicted with confidence.

The CP and FS are crucial in maintaining the highest level of factory control, making efficient use of the bottleneck sections using this global approach[3] for each product. Predicting how changes affect bottlenecks such as new product released into the factory and released for service on a particular machine group in the factory is the goal of the CP and FS. The theoretical cycle times (Fig.4.)

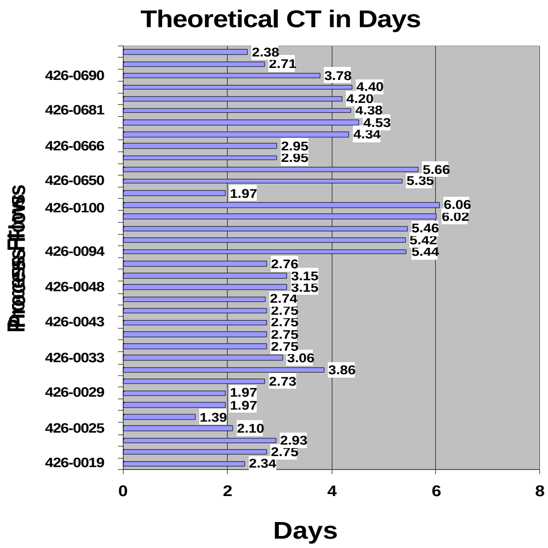
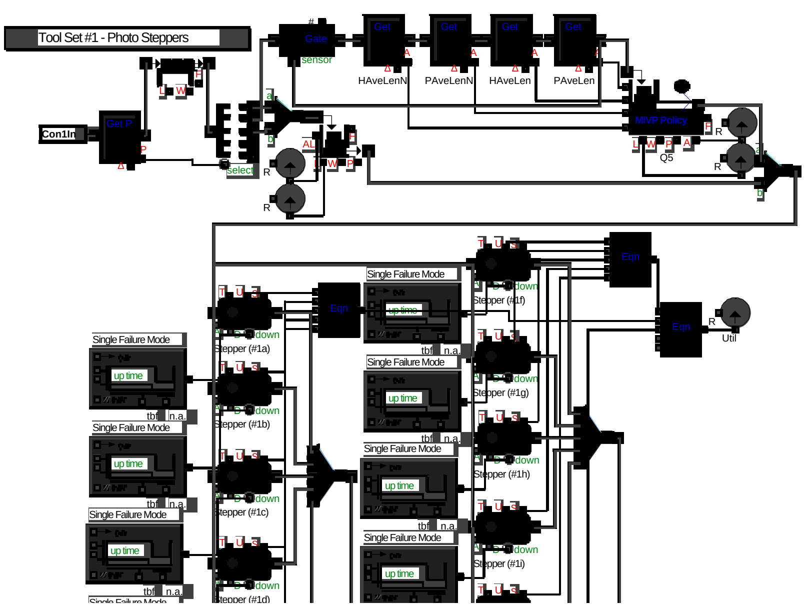


Fig. 4. Theoretical Cycle Time Chart

are calculated for each process flow for use in comparison with the estimated cycle time when more than one product is on the floor at the same time. The bottleneck for one product may not be the bottleneck for a second product. A third bottleneck may occur when the two products are mixed on the production floor at the same time.

Figure 5. FS Icons Photo Bay

(Extend + Manufacturing Screenshot of a Simulation Model)



The FS uses FIFO and "Hot-Lots" as the resource scheduler with MTBF and MTTR from historical data. Icon based simulation software was used to build the FS because of its custom libraries that represent scenarios on the factory floor (Fig. 5).

Conclusions

To achieve the shortest cycle times in a multiple product FAB we must determine the optimal WIP based on the production mix. Because of the complexity in semiconductor multiple product manufacturing a CP (snapshot) is limited as shown in Table 1 resulting in difficulties when trying to proactively predict and control WIP to achieve desired cycle times and meet delivery dates of all products. The main limitation of a CP is that it calculates the optimal WIP at a moment in time, when the production mix changes the CP must be recalculated. The addition of a FS to an existing CP allowed planners superior control of their FAB and increased on time delivery to their customers by helping the FAB planner to dynamically achieve an optimal WIP (a constantly moving target). It maximized throughput by recalculating the optimal WIP for achieving the shortest cycle times possible dynamically. The FS and CP combination permits the operational planner to introduce new product into an existing production mix with confidence as to the customer deliver dates and FAB Capacity. The result for multiple product FABs is an increase in control of production by giving the FAB planner a superior tool to hit the moving target of optimal WIP to achieve the shortest cycle times possible.

[1] D.W. Collins, K. Williams and F.C. Hoppensteadt, "Implementation of Minimum Inventory Variability Scheduling 1-Step Ahead Policy in a Large Semiconductor Manufacturing Facility," in the *IEEE 6th International Conference on Emerging Technologies and Factory Automation Proceedings*, *UCLA*, Los Angeles, Sept. 9-12, 1997, pp. 497-504.

[2] D.W. Collins, "Inventory modeling yields significant cycle-time improvements," *Journal of Solid State Technology*, Vol. 42, No. 1, January 1999, pp. 44-48.

[3] D.W. Collins, T. Torsina and R. Balgemann, "A Simulation Study to Compare Minimum Inventory Variability Policies (MIVP®) and First-In-First-Out (FIFO) Algorithm" *Proceedings of the IFAC'99, 14th World Congress of IFAC International Federation of Automatic Control*, Beijing, China. July 5-9, 1999 pp. 461-466.

[4] D.W. Collins, F. Golshani, F. Hoppensteadt, C. Ringhofer, J. SI and K. Tsakalis, "Interdisciplinary Research on Modeling and Scheduling of Semiconductor Manufacturing Operations," *Proceedings of ASEE'2000 Conference*, St. Louis, Missouri, June 18-21, 2000.

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