

PRODUCTIVITY MODELING OF SEMICONDUCTOR MANUFACTURING EQUIPMENT

Mark Pool
Robert Bachrach

Applied Materials, Inc.
2861 Scott Boulevard
Santa Clara, CA 95050, U.S.A.

ABSTRACT

Optimizing a semiconductor wafer fab requires balancing technology and productivity. Recent work on productivity modeling will be described and focus on discrete event simulation models of unitary tool, modules, and whole fab. In addition, some related cost-modeling aspects will be presented. The Applied Materials Turbo Modules Environment is reviewed. Turbo-Modules Unitary Tool Models (UTM) were developed for determining a configured tool's performance, and the Tool Group Models (TGM) were developed for exploring module and fab modeling. Turbo-Modules is based on AutoSimulations, Inc. (ASI) AutoSched AP's open architecture and a customized Graphical User Interface (GUI). The presentation provides a case study performed to analyze the loss of accuracy in a tool group model by modeling unitary tools as black box. Some fab cost modeling will be discussed.

1 INTRODUCTION

The Applied Materials Turbo-Modules Simulation Environment is briefly described and software roadmap for future development is presented. Turbo-Modules is based on ASI's products: AutoSched AP, AutoMod with Model Communications Module (MCM), AutoView, and AutoStat on top of Windows NT™ (4.0) operating system. In addition, some customization exists in our standardized Applied Materials Extensions.

Turbo-Modules sought the simulation rate capabilities of AutoSched AP while keeping the visualization capabilities important to material movement studies. Recently the Applied Materials Turbo-Modules Simulation Environment was re-aligned with standard ASI products in order to improve maintainability and to take advantage of new features. Unitary Tool Model (UTM) currently exists for many of Applied Materials' family of products. The UTM's are used to determine a configured tool's performance, and analysis of scenarios that arise. The

Applied Materials Tool Group Model (TGM) is used to model tool behavior within semiconductor material flow of the manufacturing factory (fab).

Turbo-Modules is layered on top of AutoSched AP. The application interface is a Microsoft Foundation Class (MFC) based tool that utilizes Excel™ to provide data and factor input to the model, as well as present results of simulation runs and analysis. The data input and output uses terminology common in semiconductor equipment manufacturing, limiting the simulation experience required of the user. The application is used internal at Applied Materials primarily for capacity analysis to evaluate equipment performance for specific cluster tool configurations.

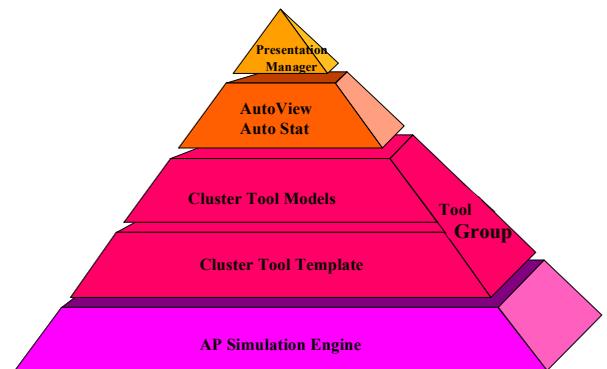


Figure 1: Model Architecture

Individual users log into Windows NT™ and to the model. The login procedure ensures that each user is attached only to their unique database. After logging into the model, users create either a new case, copy a previous case, or select from previously defined cases. The Case Select window provides easy and convenient selection between tool group and Applied Materials' tools and then among specific cases within that tool selection. The case name defines a specific use of the tool or fab. Naming conventions are at the discretion of the user. Differences in

cases can be vast (different tools) or as simple as a minor parametric change. After selecting a case the user can either run the model or edit associated input data. Turbo-Modules also allows the user to run several cases simultaneously.

2 DATA MANAGEMENT

Microsoft Excel™, launched through the MFC interface, presents the UTM custom data I/O, allowing users to modify model parameters. A case is defined in a single workbook with each of the sheets containing parameters and options used to represent the equipment being modeled. Excel™ is used for data input, setting up experiments, and reviewing simulation results. Single factor or multi-factor experiments can be established to provide data for sensitivity test. Certain experiments have embedded optimization to determine what the optimal settings are for factored input. The interface is common between all tool models within the UTM. While the TGM is different from UTM, because of the inherent differences of fab and tools, the data I/O design provides continuity between UTM and TGM. Therefore, a UTM user will find the TGM data interface somewhat familiar.

3 DATABASE OVERVIEW

When the user is finished inserting, deleting or modifying UTM, data is saved to a MS Access™ relational database. This structure enables a library building of cases for future use. A “Local” database, automatically created for each user, is accessed during login and captures the user specified data. The user also has read-only access to data within a “remote” database. The remote database contains parameters that are common to all users, thereby providing default, standard and reference data. Portions of the user’s case data will likely be in both the user’s local database as well as in the remote database. The system model administrator has control of user accessibility within the local and remote database. The saved UTM data is used directly by the AutoSched AP simulation engine.

One of the objectives of using the database was to achieve enhanced case execution rate for sensitivity analysis. Turbo-Modules can execute up to 60 cases per minute.

The TGM user may also choose to develop, run and review TGM models. When the user decides to enter the TGM, the first sheet to be edited is usually the Station table. The user can select to insert tools that were run in the UTM; thereby accurately capturing low level details that will affect overall factory performance. The Tool Family List is the second sheet generally manipulated by the TGM user and groups tool types into function or process groupings. The third sheet, which usually consumes the most user time, is the Process Table. The process table defines the process (routing or product) flow, which can be

of any length; from a few steps to multiple products of several hundred steps each, including re-entrant, metrology, line-yield and other fab level parameters.

Because of the complexities and voluminous data details of the Turbo-Modules UTM and TGM models, cases and associated data are automatically correlated and controlled via use of MS Access™ database.

4 DETAILED MODELS AND FLEXIBILITY

A powerful capability of the Turbo-Modules TGM is the ability to simulate Applied Materials’ tools in great detail within the fab model. There are three modes of operating the TGM:

- Detail Tools - automatically uses UTM input data, simulates and visualizes (animation) all UTM details (robots, wafers, etc.) in TGM
- Gray Box Tools - use UTM output summary data, but does not use UTM details and does not visualize all UTM details within TGM,
- Black Box Tools - data entered directly in TGM, no UTM data used for fab model, no UTM visualization in TGM

These three TGM modes provide flexibility and inter-mixing of modes for appropriate input details, as well as the desired level of modeling output desired. Because semiconductor factories are complex, it is not always appropriate to model and simulate every detail, nor conversely to ignore detail. The selectable detail, gray and black box mode implemented in TGM provides model flexibility for various studies.

5 ANIMATION/MATERIAL HANDLING

One of the primary goals of using the UTM/TGM models is the ability to perform analysis and provide visualization of various scenarios that would be useful in decision-making. The AutoSched AP engine reads the model input parameters, executes the simulation run and writes the output including throughput, utilizations, event logs, transfer times, and more. Applied Materials’ previous TGM implementation (AP5.5) was extensively customized to incorporate features Applied Materials found critical, which were not offered in ASI standard product. One of these custom features was publication of detailed material handling event records for use by AutoView so Applied Materials could visualize the simulated case. The visualization was independent of the AP engine, thus the user could repeatedly view the simulated events, without actually re-running the simulation. As part of the recent Applied Materials upgrade to AP6.2, the TGM was better aligned with the standard AutoSched AP product, thereby considerably reducing customization and maintenance. This

required eliminating the database component pending AutoSimulations offering this capability as a product. These modeling environments are shown in Figures 2 and 3.

The TGM database loss is primarily a case management inconvenience, since the larger TGM do not need the high case rate.

UTM's are used for determination of a tool's configured throughput, and various 'what-if' scenarios. The TGM provides detail tool level modeling of the semiconductor material flow of the manufacturing factory (fab). The TGM uses AP for its speed in simulation of fab manufacturing and scheduling while using AutoMod for material handling. The UTM uses a mixture of AutoMod and AP for detailed material handling and animation. However there will be an improved capability through extensive use of AP, MCM and AutoMod to integrate the

UTM details and increased material handling animation into more complex TGM. It is Applied Materials' vision to have increased ability to enable the user to select and "roll up" more UTM details into the TGM. The model building block and roll up continues to provide accurate input and analysis of low level details in higher-level models.

Applied Materials' recent model upgrade enables better use of ASI Material Handling Systems, VR Graphics, and increased communications to TGM (AP) via sockets (TCP/IP). The recent upgrade will in the future enable use of the Publish/Subscribe Message Utility, Network IPC (TCP/IP sockets) and the AP/AM roadmap for use of Distributed Component Object Model (DCOM, Microsoft Protocol) as well as other emerging technologies.

6 CASE STUDY

A key issue in using complex models such as Applied Materials' TGM with detailed mode capability is to know if the detail model provides the same results as the standard AP6.2 simulation. A study was conducted and results compared of modeling detailed tools to equivalent gray box tools using Applied Materials TGM AP6.2 upgrade. The study investigated effects of running Detail and Gray models with deterministic and then random unscheduled down time (same random number stream for random events). Preliminary results are provided in Table 1, Table 2, and Figures 5 and Figure 6, below.

Table 1: Result for Deterministic Down Times in Detail and Gray Models

Model	Run Time (min:sec)	Avg. WIP (lots)	Avg. Cycle (hr:min:sec)	Eqp.Util (%)
Detail	2:04	1.78	9:51:32	36.07
Gray	0:02	1.78	9:51:09	36.06
Accuracy		100.00%	99.93%	99.97%

Table 2: Result for Random Unscheduled Down Times in Detail and Gray Models

Model	RunTime (min:sec)	Avg. WIP (lots)	Avg. Cycle (hr:min:sec)	Eqp.Util (%)
Detail	15:17	20.95	25:07:32	50.13
Gray	0:10	21.51	25:47:55	50.07
Accuracy		97.4	97.4	99.9

The case study results show:

- There is no significant loss of accuracy between Gray and Detail Modes in Deterministic or Random cases.

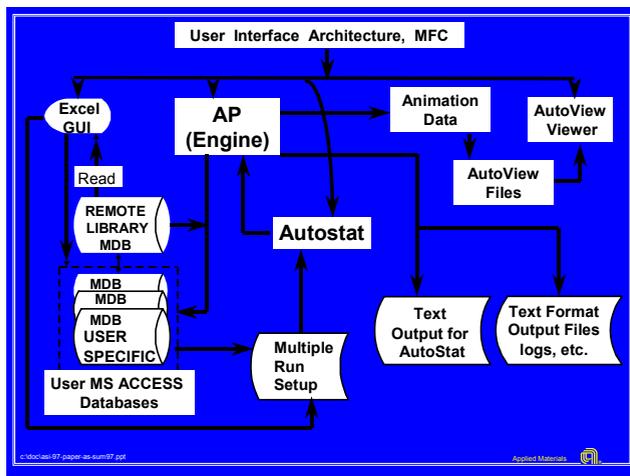


Figure 2: The Original Modeling Environment with Applied Materials Customization

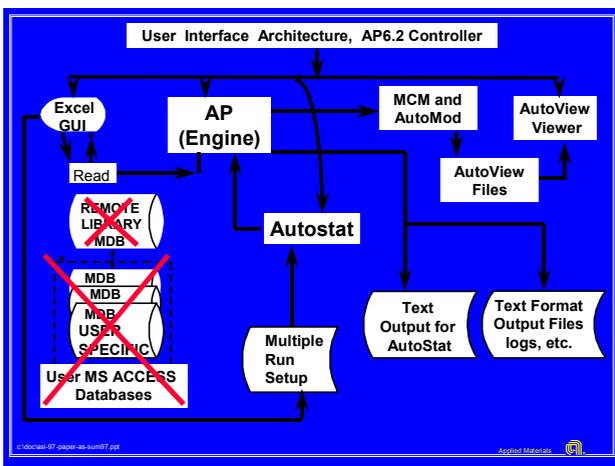


Figure 3: The Upgraded Modeling Environment with Applied Materials use of AP6.2 Controller For TGM (note-UTM continues to use the database)

- There is a significant (>90 x) reduction in model run time between Gray and Detail Modes.

In addition, using the model’s automated data collection between detailed UTM and TGM models provides a tremendous benefit to minimization of data entry errors. The automation, by virtue of the data “roll up”, provides accurate input of low level details in higher-level data intensive models.

7 FAB COST MODELING

Manufacturing equipment must not only be technically capable, but must also meet requirements for cost and productivity. Cost of Ownership (COO), provides a complete picture of manufacturing costs associated with a single tool operating in a fab. Wafer Cost models are an extension concerned with costs of processing a wafer from start to finish in the fab, provide key indices for and understanding of overall manufacturing costs. This type of modeling provides “what-if” scenarios for evaluation of the impact made by various tools across the entire fab and on the final product, and the completed wafer. Wafer cost modeling and its uses will be discussed.

8 SUMMARY / FUTURE WORK

The Applied Materials models described in this paper continue to provide in-depth detailed understanding of various complex-manufacturing problems. It is Applied Materials’ vision to have increased capability to enable the user to select and “roll up” more details into the TGM.

The model building block and roll up continues to provide accurate input and analysis of low level details to higher-level models.

Applied Materials’ recent model upgrade enables use of standard features of the base-modeling package provided by ASI. In the near future, because we have standardized to current AutoSched AP and AutoMod we will be able to make use of the Publish/Subscribe Message Utility, Network IPC (TCP/IP sockets) and the AP/AM roadmap DCOM and other emerging technologies.

Because Applied Materials uses the simulation to investigate many different scenarios, case management and automated data management continues to be important. We believe product developed, maintained and integrated repository like database would provide significant benefit to simulation and model users as depicted in Figure 4.

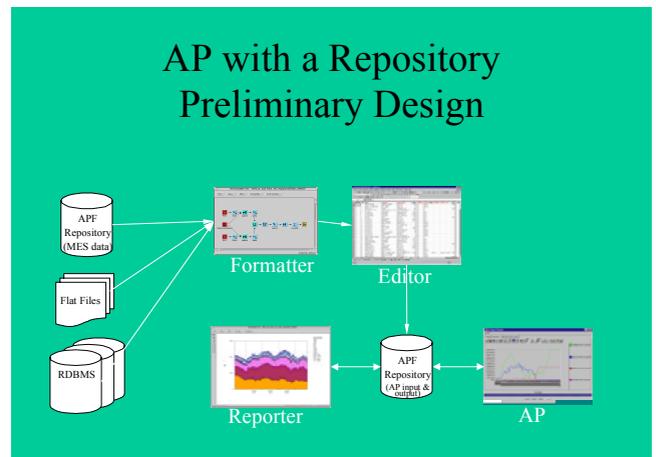


Figure 4: Database for Case Management

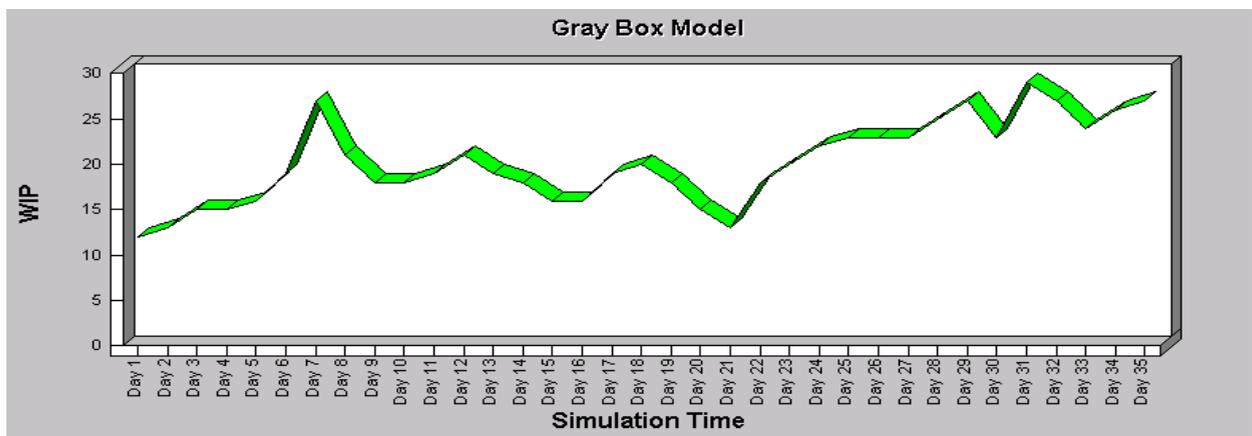


Figure 5: WIP Levels in Gray Model

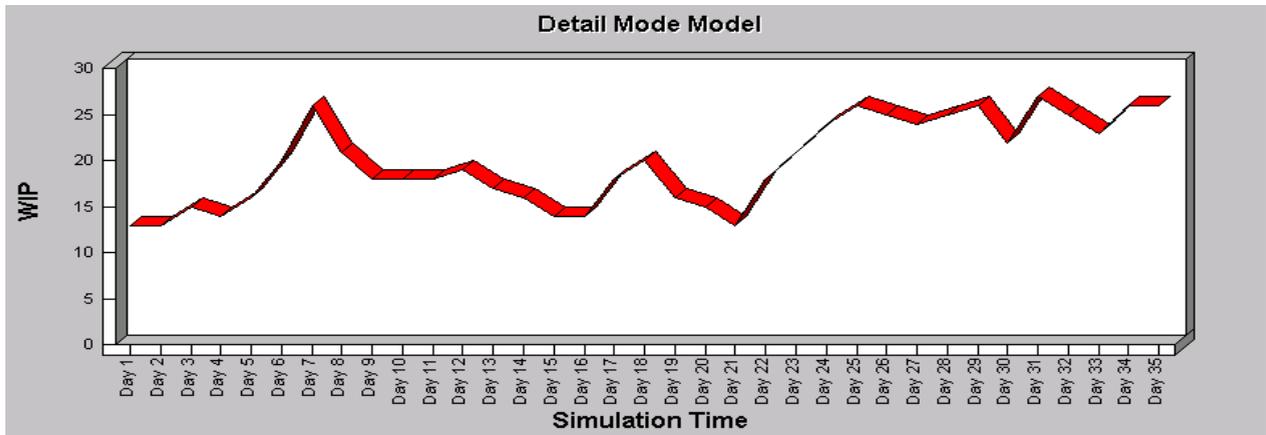


Figure 6: WIP Levels in Detail Model. Notice the Near Exact Signature Between Gray and Detailed

AUTHOR BIOGRAPHIES

MARK POOL has been analyzing manufacturing systems since 1982. Mark is currently Technology Programs Manager at Applied Materials. Mark received his education at U.C. Berkeley in Chemical Engineering, Education and History. Mark has held positions as a research engineer and technician in semiconductor processing and manufacturing, and as a successful independent contractor. Mark has held engineering and technical positions at Applied Materials, In-Motion Technology and Lawrence Livermore Laboratories. His email is <Mark_Pool@AMAT.com>.

ROBERT BACHRACH is Senior Director of Strategic Technology Programs at Applied Materials. Bob has worked with various aspects of semiconductor and thin film deposition, epitaxial growth, and characterization of both metals and related devices. Bob is a fellow of the American Physical Society and Sigma Xi. He has published over 175 journal articles, 6 book chapters, and edited a two-volume book published by Plenum Press. Bob has previously held positions at Stanford University, Xerox Palo Alto Research Center, and Bell Laboratories. His email is <Robert_Bachrach@AMAT.com>.