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Simulation in Semiconductor Manufacturing Facilities

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Abstract

Semiconductor manufacturing is one of the most complex industries in terms of technology and manufacturing procedure. The life cycle of a semiconductor facility (FAB) has many phases, in their life cycle including capacity planning, new products introduction, variation of products/technologies, and decline phase. The complexity of the manufacturing and the external forces from markets and technology growth make predicting the effects of changes in the manufacturing system problematic. Simulation, if used correctly, is a powerful hands-on tool which may be used to give a better insight of the effect of engineering/management decisions on the performance of the manufacturing system. While not a panacea for sustainable performance, simulation provides an effective vehicle for defining the path from competitive concepts to real world solutions and gives an opportunity to experiment with, and assess the impact of, production plans, aiding the management and production teams' decisions.

This paper presents some examples of simulation applied to semiconductor manufacturing for performance improvement and costs reduction. Integrating Simulation with Operations Research (OR) and Artificial Intelligence (AI), promises to significantly improve the ability to address complex problems for highly complex manufacturing facilities.

Keywords: Simulation, Semiconductor Manufacturing, Production Planning

1. Introduction

The semiconductor manufacturing (SM) industry is characterised by a number of trends (e.g. high product quality, short lead time, low cost) that affect the way in which manufacturers have to plan in order to successfully competing in today's tight, competitive and volatile market. Confronted with the opportunity of moving from 200 to 300 mm wafer processing technology, the dual promises of more chips per wafer and economies of scale have led the development of the new 300 mm fabrications despite the added cost of complexity in facility design and process planning [1].

The capital cost to build and equip a wafer fabrication plant (FAB) has increased exponentially over time from approximately \$6 million in 1970, to in excess of \$3 billion by 2002, see Figure 1. As the chart indicates the current trend in costs predicts that the cost will exceed \$10 billion by 2007, and may reach \$18 billion by 2010. The magnitude of the cost factor puts extensive pressures on management to question whether, under the current industry dynamics, production can continue [2].

A FAB usually goes through many phases in its life including, factory layout design, factory construction, process selection and design, start-up and full production, all of which require careful planning at many levels.

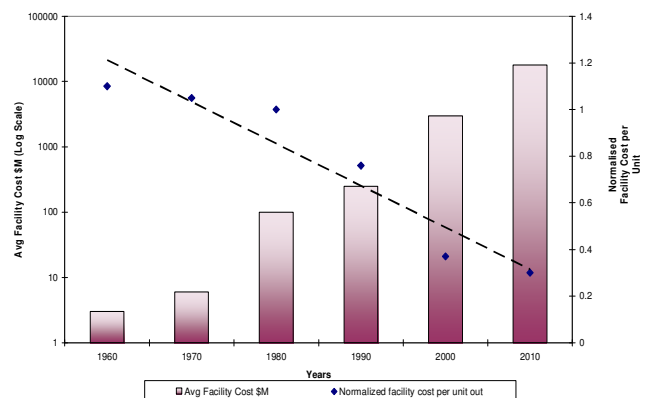


Figure 1. Facility cost trends, IC Knowledge 2004[2]

Wafer fabrication is the most technologically complex and capital intensive stage of semiconductor manufacture. It involves the processing of silicon wafers to create the semiconductor devices in the wafer and build up the layers of conductors and dielectric on top that provide complex interconnection between devices. Hundreds of operations are required to build a complex component such as a microprocessor. The main areas in wafer fabrication are shown in Figure 2 with photolithography, the most complex operation, requiring the greatest precision [3].

The need for an effective and powerful approach for capturing operational information and analysing SM systems to support critical planning decisions has increased with the complexity of the products and the cost pressures on manufacturing. This paper discusses some of the challenges which face the semiconductor industry in particular in planning activities and presents examples of the application of simulation to SM, as an approach that provides an effective tool for defining the path from competitive concept to real world solution. Simulation allows experimentation with a model of a system, instead of risking production loss and disruption on the real one.

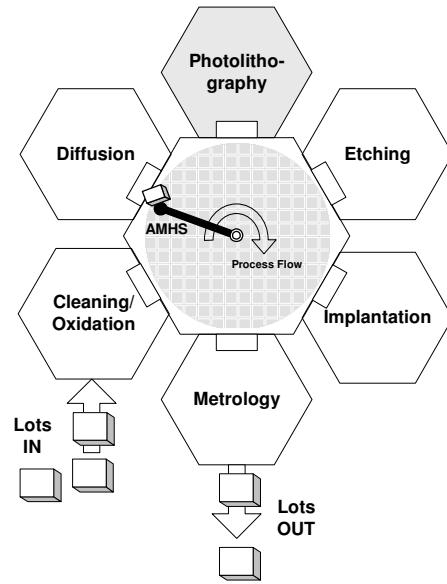


Figure 2. Main Processes in Wafer Fabrication [3]

2. Challenges in the Planning of Semiconductor Manufacturing

There is considerable amount of literature in the area of SM planning. Uzsoy *et al.* [4]&[5] provide an exhaustive review of production planning and scheduling models. They classify research into three broad areas: performance evaluation, production planning and shop floor control.

While fab design is difficult in itself, there many other challenges in SM which result from a high product-mix, re-entrant flow, and parallel equipment using different technologies which combine to make production planning a major task in this environment. To further complicate matters, the flexible manufacturing tools are extremely expensive (both in capital and running costs) and hence there is no possibility to experiment within the facility. Some of these planning challenges are briefly discussed below:

Product/Technology Life Cycle:

Technology in semiconductor processes changes rapidly in order to achieve better quality at lower cost (Figure 3). Product and production technology life cycles are becoming shorter, with new products being introduced continually into a facility. This leads to additional pressures on management to achieve maximum profit in shorter times before the product and/or technology begin to decline. Forecasting of future demands for particular wafers is getting even more difficult requiring the industry to develop yet shorter lead times on orders.

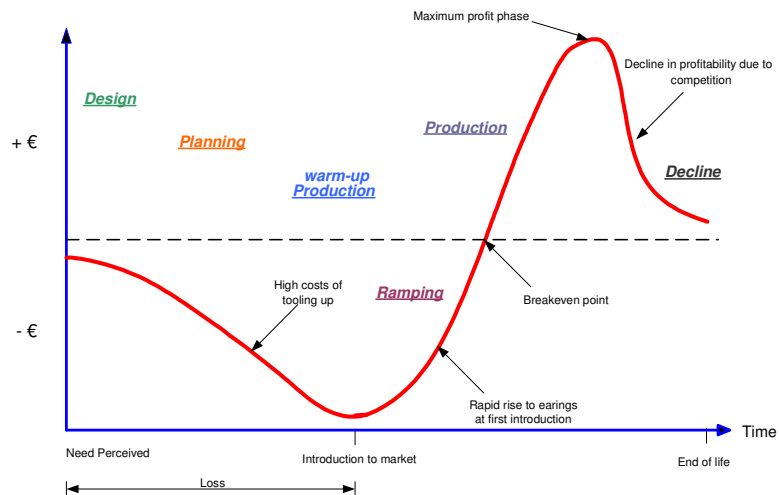


Figure 3. Product life cycle in semiconductor fabrication

Product Types: In today's environment, manufacturers achieve competitive advantage by offering a variety of high quality products. To ensure high utilisation of capital intensive production machinery the life of a FA is extended

by using flexible tooling which can deal with a number of different products simultaneously (the product-mix). The changes to tool settings and production sequences for each different product increase the variability in the production system significantly. The fact is that “The higher the product-mix the higher the variability in the production system”[6]. In addition, New Product Introduction (NPI) may also require new tooling and equipment in addition to sharing available resources.

Capacity Planning: The rate of changes in product-mix and NPI makes estimation of future requirements for capacity in the manufacturing system difficult. Further, the long lead times associated with procuring new tools mean that there is a large time lag between planning and start of useful production. To minimise the gap between planning and availability for all the tools, planners have to go through a combinatorial problem of all possible production schedules.

Scheduling Problems: The variations in product-mix, re-entrant flow, and parallel equipment using different technologies made it difficult to guarantee delivery reliability (i.e. the ability to meet due date commitments).. To complicate scheduling further, new schedules must be evaluated and optimised and prepared for implementation without disrupting the existing flow of product through the plant. This demands a high level of confidence in the analysis and predicted performance of the FAB before any changes can be made at floor level.

Customer Orders: While semiconductor users require high quality products, the demand for a particular product is unpredictable in most cases and orders can be lost if the manufacturer does not have sufficient capacity during a period of high demand. The lead time for order delivery and the lead time required by manufacturing often require outsourcing of production to meet demand, indeed throughput time for complete manufacture may exceed the time between order confirmation and delivery requiring wafer processing to start before ordering if due dates are to be met. This leads to massive quantities of work-in-progress (WIP) which must be stored in the FAB [7]. As a result, there is now great pressure on the reduction of cycle time, with huge savings possible as the value of partly processed WIP is high.

Manufacturing Environment: The fab environment is stochastic due to process yield variations, dynamic product-mix, production ramping, maintenance programs, production control policies and many other factors. The lead time for getting a product to a particular tool could range from 48 hours to several weeks depending on the current configuration of the plant. The planner has to consider which tools should be assigned to particular processes which may be product and/or layer dependent. Capacity planning in such stochastic environments using simple linear models can be highly inaccurate. Further, the implementation of policies on the FAB floor relies on the co-operation of local workers who may have no understanding of the impact of their actions on the overall system.

Bottlenecks: The fab bottlenecks, or problem zones, are often accompanied by a build-up of WIP in front of the zone. The cost of this unnecessary WIP in the system is twofold; storage and increase in throughput time for those wafers. The simple approach of purchasing additional processing tools is expensive and may only result in moving the bottleneck to another location. New strategies for management of WIP in FAB's must be developed to enable planners balance the levels required to meet customer demands and those which maximise the speed of product flow through the FAB.

Within this complex environment greater pressure is being brought to bear on production management for:

- Faster and better decisions are expected with the exponential growth of information and knowledge management capabilities.
- Shorter lead time for introduction of higher quality products with guaranteed delivery dates
- Accurate adaptive schedules to cope with the dynamic nature of production systems.

3. Applications of Simulation to Planning for Semiconductor Manufacturing

Traditional industrial engineering analysis techniques using deterministic models to study manufacturing systems are simply not adequate to analyse complex environments such as semiconductor manufacturing [8]. There is, therefore, an immense need for effective and powerful approaches which can capture and analyze manufacturing systems to support these decisions. Simulation allows experimentation with a model of a system instead of experimenting with the real thing, which might cause production loss and disruption [4].

Manufacturing simulation has become one of the primary application areas of simulation technology [10]. It has been widely used to improve and validate the designs of a broad range of manufacturing systems. Typically, manufacturing simulation models are used to predict system performance or to compare two or more system designs or scenarios. For existing FAB's the greatest potential for simulation lies in sensitivity analysis of operating policies, with a focus on meeting production goals while avoiding new equipment purchases. There is particular benefit to come from a better understanding of the impact of product-mix changes and production volumes on the capacity and performance of the system [11].

On the other hand for new FAB's, simulation may be used effectively to evaluate and analyze solutions for equipment layout, material flow, and automated material handling systems to minimize tool count, WIP, and cycle time. Each level in Figure 4

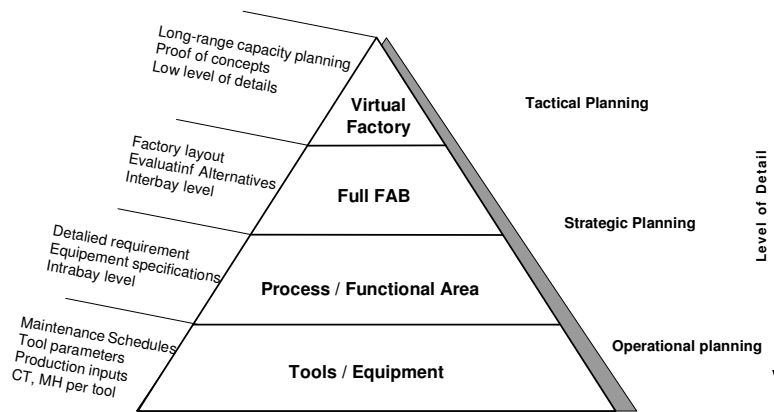


Figure 4. Variation in level of detail with application of a model

represents a distinct area where simulation may be applied. At the base, detailed models can be built which reflect the performance of an individual tool or piece of equipment. As the tools used are flexible, these models are often complex and may contain queues and parallel processing, acting as a manufacturing system in their own right. At this level of detail good correlation of all aspects of the workflow is expected

Simulation is extensively used in SM planning (Figure 5). The reasons for this are the intractability of detailed analytical models of the SM process, the uncertainties inherent in the manufacturing process itself, and the steady improvement in computer technology which makes building simulation models easier and reduces the risk and the computational expenses.

Simulation models can also be developed at different levels of detail: a highly detailed model of a particular process step or workcenter, or more aggregate model of an entire facility or sub-system. The focus in this paper is on scheduling and planning aspects in SM. Considerable effort

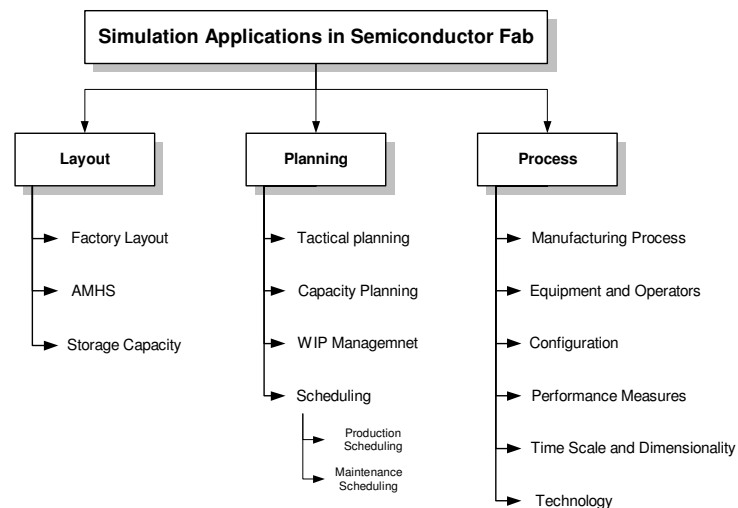


Figure 5. Applications where simulation may be used in semiconductor FAB's

has gone into the development of simulation models for wafer fabrication and their use in analyzing the effects of different control strategies and equipment configurations [6].

Semiconductor FAB's are, typically, automated flexible manufacturing installations containing parallel process paths with highly re-entrant flow and thousands of simultaneous production lots. As a result, simulation projects within may vary in terms of information about each structural element (process, tool, material handling etc.) but must maintain dynamic records of the state of each lot as it moves through the FAB. Such a record may contain a number of key parameters relating to the performance of the system. The number of dynamic variables in a full FAB model will therefore be at least on the order of some polynomial of the number of lots in the factory. It has been clearly shown that the calculation time for such models increases exponentially with the size of the system being simulated [12]. Figure 6 shows the areas where the simulation has been successfully applied to scheduling problems and outlines the factors which may be used as inputs or outputs from the models.

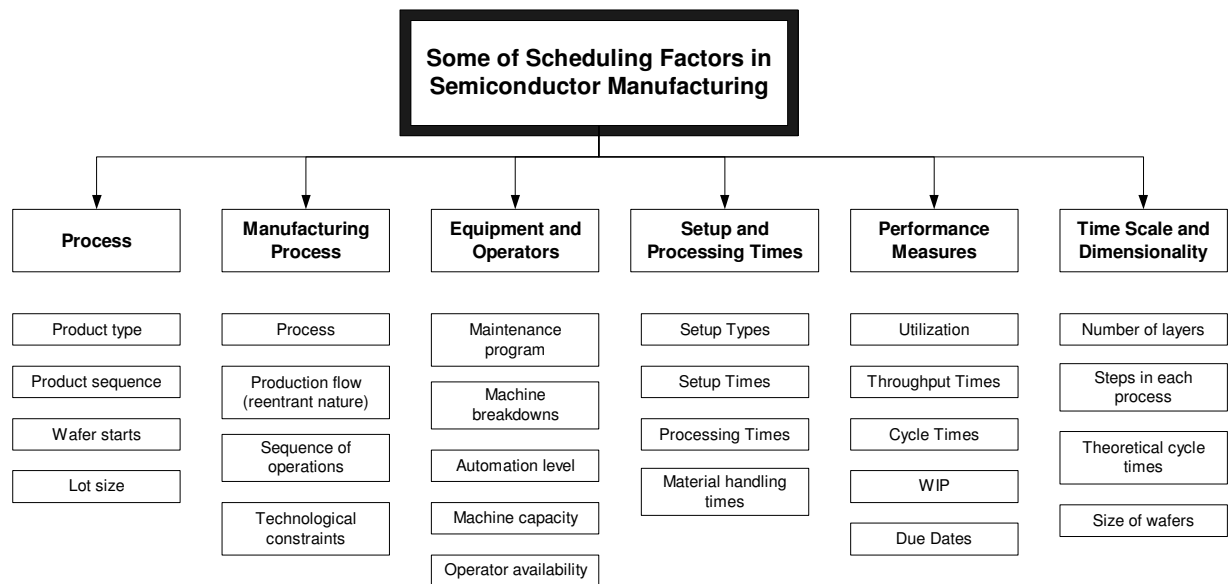


Figure 6. Factors in which simulation models have been applied to in scheduling of SM

The application of simulation to solve scheduling issues is not simple as each problem must be addressed on its own merits; however there are essential steps which are common to all such activities [10]. In addition, it must be clearly understood that, simulation alone cannot provide the solution as it is simply a tool for evaluating the behaviour of the system in response to external influences. The keys to successful application are a quality model which provides an accurate representation of the actual system and a structured approach to the modification of input parameters to optimise the performance of the system.

4. Pointers in the Application of Simulation to Manufacturing

While it beyond the scope of this paper to review the details of the analysis and outcomes of individual simulation studies, a review of the approaches taken and the relative success has been combined with direct experience to identify key areas which show the benefits of simulation over other forms of analysis and the dangers which may reduce the effectiveness of the solutions obtained. These are often compounded as the analyst must rely on the client to provide quality input data and must explain the implications of the results to others who have little understanding of the principles of manufacturing or the limitations imposed by assumptions enforced to provide a timely answer. A brief evaluation of the main advantages and pitfalls is given in Table 1.

Table1. Simulation Projects Advantages and Pitfalls

Advantages	Pitfalls
<ul style="list-style-type: none"> - Most complex, real-world systems with stochastic elements cannot be accurately described by mathematical models that can be evaluated analytically. Thus, simulation is often the only type of investigation possible. - Simulation allows the estimation of performance of existing and virtual systems. - New hardware designs, physical layouts, transportation systems...etc. can be tested. - Time can be compressed or expanded to better observe the phenomena under investigation. - Insight can be obtained into the interactions between, and the importance of, internal variables. - Provide a better understanding of how the system really operates rather than how individuals think the system operates. - "What-if" questions can be answered, useful in the design of new systems. - Proposed alternative system designs can be compared. 	<ul style="list-style-type: none"> - Failure to have a well-defined set of objectives at the outset. - Failure to communicate with the client on a regular basis. - Poor application of simulation methodology, probability and statistics [13]. - Inappropriate level of model detail. - Failure to collect good system data. - Belief that so-called "easy-to-use" simulation packages require a significantly lower level of technical competence. - Selection of an inappropriate simulation approach [6]. - Misuse of animation. - Failure to perform a proper output-data analysis. - Accurate simulation models are often expensive and time-consuming to develop. - Sometimes an analytical solution is possible, or even preferable.

5. Integrated Simulation Tools

As mentioned previously simulation can only replicate the behaviour of the system under observation and cannot, in and of itself, provide improvements in the performance of the system. It does however offer a suitable method for assessing the effect of control parameters on the behaviour of the system. In response to a particular set of inputs, the model provides an output which can be used to measure the performance of the system. The inputs are decision variables, and simulation outputs are used to model an objective function and constraints for an optimisation algorithm. The goal is to find the optimal setting of the input factors to achieve the best output from the system. To this end, simulation is now being combined with other operations research and/or artificial intelligence techniques outlined in Table 2. Further, simulation software is designed to include these elements within the modelling, providing a single user-interface which can allow the developed model to be used more widely.

Table 2. Examples of Hybrid techniques reported in literature [6]

Author(s)	Hybrid Techniques	Notes
Sereco <i>et al.</i> [14]	KBS	Optimization techniques, hierarchical planning, and heuristic search
Dagli <i>et al.</i> [15]	Lawler's Algorithm & NN	Algorithm generates schedules to train NN
Rabelo <i>et al.</i> [16]	ES & NN	IFMSS: intelligent FMS scheduling, expert system and a back propagation NN
Rabelo <i>et al.</i> [17]	IFMSS	Enhancing the model with adding simulation and GA to his control architecture
Yih <i>et al.</i> [18]	AI& Simulation	Hybrid model of AI and simulation for a small set of candidate scheduling heuristics
Yih <i>et al.</i> [19]	Semi-Markov & ANN	Semi-Markov optimization and ANN for robot scheduling in a circuit board production
MacCarthy <i>et al.</i> [20]	LP & Simulation	Rule-based framework; mathematical optimization procedure and simulation.
Sim <i>et al.</i> [21]	ES & NN	Expert system to train NN to reduce the time required for training.
Szelke <i>et al.</i> [22]	CBR & Machine Learning	Reactive learning of machine for shop floor scheduling
Kim <i>et al.</i> [23]	Inductive Learning & NN	Multi-objective FMS schedulers
Lee <i>et al.</i> [24]	GA & Machine Learning	To generate empirical results using machine learning for releasing jobs to the shop floor and GA to dispatch jobs.

6. Conclusions

Semiconductor manufacturing is a very competitive environment where the demands of the market place a huge importance on achieving maximum performance from a cutting edge, highly flexible manufacturing system. In this environment, simulation is an essential tool as semiconductor factories are too large, too complex, too dynamic and too costly to optimize and refine by any other means. As this is a relatively new field and solution techniques are still under development, confidence in this approach to factory optimisation is still low and:

- It is critical that simulation models provide meaningful data in a timely manner. This depends primarily on accurate system analysis, input data accuracy, model building and validation. It is also essential that the model be kept up-to-date in order to reflect the current factory scenario. This can be accomplished by having a good, user friendly interface between simulation model and manufacturing users.
- “Credibility is not a gift – it has to be earned” and is built up one step at a time, supported by facts and consistency. Further, “credibility is never owned; it is rented, because it can be taken away at any time” [8]. Researchers must therefore focus on providing robust industrial models with quality outputs.
- Based upon authors’ industrial experience, they provided a protocol to follow for simulation projects which includes a systematic methodology for optimizing simulations [6]. As part of this, the initial stages concentrate on delivering measurable concrete results to provide confidence in simulation.
- The dynamic nature of manufacturing requires that the models, once developed, should be easily re-used and reconfigured by those who know the system best, the manufacturing engineers.
- Many operational decisions are made in semiconductor manufacturing based on prior knowledge, experience and intuition. The need of reliable decision support systems brings a new dimension of integrated tools of simulation and optimization to provide better and effective solutions.

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