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CRITICAL TOOLS IDENTIFICATION AND CHARACTERISTICS CURVES CONSTRUCTION IN A WAFER FABRICATION FACILITY

Dima Nazzal

School of Industrial Engineering
and Management Systems
University of Central Florida
Orlando, FL 32816, U.S.A.

Mansooreh Mollaghasemi

Department of Industrial Engineering
and Management Systems
University of Central Florida
Orlando, FL 32816, U.S.A.

ABSTRACT

The purpose of this research was to identify the factors in a wafer fabrication facility that significantly affect the cycle times of two main technologies that are currently in process and in demand for the next few years. Moreover, the goal was to construct the characteristics curves that would provide information about the different capabilities of a wafer fabrication facility for several improvement scenarios.

A valid simulation model of the whole production line of the fabrication facility was built. The input factors in the fab that significantly affect cycle time, were identified through factor screening experiments. Based on these factors, several scenarios involving addition of tools, were identified and the characteristics curves were constructed for each scenario. These characteristics curves were used to relate cycle time to production volume capacities.

1 INTRODUCTION

In the highly competitive semiconductor industry, microelectronics manufacturers are under constant pressure to deliver higher quality, more advanced products quickly. With this competition, customer dissatisfaction will drastically affect the business status, as customers are continuously demanding their products to be delivered fast without sacrificing the quality.

The cycle time of a finished wafer is the time between the release of the wafer into the wafer fabrication facility (fab) and the time it is completed. New technologies can require up to 500 steps and take more than 40 days before a wafer is completed. The time a technology spends in development, before it is approved for production and released to the market, can take up to two years. On the other hand, a technology can stay in demand for as little as one year, after which, wafer prices drop rapidly. Based on that, semiconductor manufacturers look at cycle time as the foremost monitored performance measure in the fabrication facility.

The efforts spent by semiconductor manufacturers seeking lower cycle times are numerous and the investments to reduce their delivery times are in millions of dollars. Several studies have been directed into techniques to cut down the cycle time in semiconductor manufacturing (Page 1996, Martin 1999, Laure 1999, Kirajassoff 1993 Meyersdorf and Yang 1997, Nemoto et al. 2000 and Kramer 1989); those included adopting new scheduling policies, increasing machine and operator availabilities, continuous process monitoring and eventually investing in additional resources.

This research was implemented at Agere Systems wafer fabrication facility (formerly Lucent Technologies-Microelectronics) in Orlando. The purpose of this study is to identify the factors in the fab that significantly affect the cycle times of two main technologies that are currently in process and will stay in demand at least for the next few years. The factors that were studied here are only those that were part of the capital business plan of the company, and those were the number of machines for facility groups in the fab.

Adding machines to the critical facilities will directly influence cycle time. We measured the cycle time reduction benefits by measuring the productivity improvement using the characteristics curves, which relate the cycle time of a certain technology to the production volume.

In Section Two, the simulation model used throughout the experiments is discussed and the various interacting components of the model are described. In Section Three, the facility groups that were studied are listed. In Section Four, the factor-screening experiments performed to highlight the machines in the fab that significantly contribute to cycle time, are presented. In Section Five, the characteristics curves are constructed for several improvement scenarios proposed based on the results of the factor-screening experiments.

2 SIMULATION MODEL

The simulation software used to model the fab at Agere Systems is AutoSched AP (ASAP), a product of AutoSimulations, Inc. This is a capacity analysis, planning, and scheduling tool. ASAP can schedule most of the constraints in the factory, such as shift schedules, preventive maintenance, and operator skill classes.

The simulation model consists of several data files that could be manipulated using Microsoft Excel. Each data file includes a complete description of a certain model component (e.g., stations). These data files are all linked together to allow the logical interaction between the different model components. The main components of the model components are: stations and station Families, operators, dispatching rules, calendars, technologies, routes, and orders. The details of the model follow.

2.1 Product Mix

Two main technologies are being modeled in the study. A Technology is the term that commonly refers to a product in the fab. Products are distinguished by the technology that was used to manufacture them. Table 1 gives a brief description of the technologies modeled in this study.

Table 1: Technologies Characteristics

Technology	Wafer starts per week (WSPW)	Number of Masks	Lot Size (Wafers)
Technology 1	2775	17	25
Technology 2	1665	17	25

Lots are released uniformly to the fab according to the planned weekly wafer starts.

2.2 Workstations and Operators

A Station family is a group of identical workstations that perform the same operations. Over 100 station families process different operations around the fab; each station family consists of one to 20 identical stations. Downtimes for workstations are distributed exponentially. All station families have the same rules. Lots in front of a station family are ranked according to their priorities, with FIFO being the selection rule for processing.

Ninety-four operators are present in the fab at all times; operators are distributed around 15 areas, and the simulation model accounts for all shifts and break times.

2.3 Other Parameters

The wafer fabrication facility is a non-terminating system, and to model it accurately, a warm-up period should be allowed. Based on the technique developed by Welch (1981, 1983), the warm-up period was estimated to be 100 days. The run time of a single experiment was 300 days.

Multiple runs of the simulation were used. The number of replications depends on the confidence level required. For a confidence level of 90% per response, and two monitored responses (the cycle times for each technology), five replicates provided a sufficient level of accuracy.

2.4 Verification and Validation

The simulation model was verified using several techniques discussed by Law and Kelton (2000), such as running the model with simplified assumptions to easily detect logical mistakes and running the model under a variety of settings to ensure that the outputs were at reasonable levels.

Several techniques were used to validate the simulation model, discussed by Law and Kelton (2000), Nayani and Mollaghasemi (1998), and Sargent (1996). These included comparing the simulation model against the system's outputs for a set of identical inputs. Another technique used was to test the model under extreme conditions and ensure that the output behaved as expected. Finally, The model was presented to experts who are familiar with the fab.

3 EXPERIMENTATION

The simulation model was used to study the effects of the number of tools in a facility group on the cycle times for each technology.

After studying the queue sizes and utilization on all the workstations, seven were identified as critical: Duv Steppers, Iline steppers, Implanters, Prstrips, Scrubbers, Metal Slabs, and Sorter Cmps facility groups. To identify the significant facility groups, factor screening experimental design is performed. The number of tools in each of these facility groups is a separate factor in the screening experiments. Table 2 shows a list of the 7 factors and the coded variables accompanied with each factor.

Table 2: Description of the 7 Factors in the Experiments

Symbol	Coded Variable	Factor
A	x_1	Number of Sorter Cmps
B	x_2	Number of Duv Steppers
C	x_3	Number of Iline steppers
D	x_4	Number of implanters
E	x_5	Number of Scrubbers
F	x_6	Number of Prstrips
G	x_7	Number of Metal Slabs

4 FACTOR-SCREENING EXPERIMENTS

4.1 Fractional Factorial Design

A 2_{IV}^{7-3} fractional factorial design was performed with five replicates at each point. The design was a resolution IV design; thus, there was no aliasing between the main effects and the two-factor interactions. However, two-factor interactions were aliased with each other.

The value of the current fab model for a factor was considered to be the low level of that factor and the high level was an improvement, such as the addition of one tool. For example, if the current fab had 5 implanters, the low level for this factor would be 5 while the high level is 6.

The design generators for 2_{IV}^{7-3} are:

$$I = ABCE,\ I = BCDF,\ \text{and}\ I = ACDG$$

The complete defining relation for the design was obtained by multiplying the three generators two at a time and three at a time, yielding:

$$I = ABCE = BCDF = ACDG = ADEF = BDEG = ABFG = CEFG.$$

The analysis of variance was performed using the statistical packages Minitab and JMP with a 90% confidence level. Based on the analysis of variance for the individual terms, the following was concluded:

- The number of Duv Steppers (factor B) is an influential factor for Technology 1.
- The number of Iline Steppers (factor C) only affects the cycle time for Technology 2.
- The combined interaction effect $A*C + B*E + D*G$ is influential for Technology 1.

Testing the adequacy of the model was necessary to check that none of the least squares regression assumptions were violated. A normal probability plot of the residuals showed that the residuals were approximately normally distributed while a plot of the residuals versus their run order would test for randomness. The normal probability and residuals plots confirmed the assumptions of randomness and normality.

4.2 Design Projection

A resolution IV design would result in aliasing the interaction terms with each other. Since only 2 of the 7 factors and the interaction term "AC, BE or DG", were found significant, the design could be projected from a 7-factor design to a 3-factor design (B, C, and E). The reason for assuming that the interaction term BE is significant rather than AC or DG, was because this interaction term was shown to be significant only for Technology 1. For Technology 1, only factor B is influential while factors A, C, D and G were not.

Since we already performed 16 runs with 5 replicates each, decreasing the number of factors to 3 resulted in a full factorial design with 10 replicates at each design point. With a full factorial design we could estimate the effects of the interaction terms. The factors that were studied are:

B: number of Duv Steppers,
C: number of Iline Steppers, and
E: number of Scrubbers

After performing an analysis of variance with a 90% confidence level, we can conclude that the interaction terms BE and BCE are significant for Technology 1.

At the end of this section, based on the factors screening experiments, the number of Duv Steppers, Iline Steppers, and Scrubbers were the only main factors left to investigate out of the seven facilities with which we started. In the next section, we make use of this result to test several improvement scenarios by constructing their expected characteristics curves.

5 CHARACTERISTIC CURVES CONSTRUCTION

5.1 Characteristics Curves Description

The relationship between cycle time and utilization is usually represented by a curve called the line performance curve or the characteristics curve. These characteristics curves show a highly nonlinear relationship between cycle time and utilization and consequently between cycle time and wafers start rate.

As tool utilizations increase by starting more wafers in the fab, cycle time increases nonlinearly. At very low utilization values, there is almost no queue time, and thus cycle time becomes the summation of the raw processing times along the production line (Suri, 1998). As wafer starts increase and utilization approaches the fab's capacity, cycle time increases drastically. The characteristics curve for the fab at a certain point in time indicates the overall capacity of the fab and how well the fab is utilized. Therefore, by examining the characteristics curve, managers can make decisions concerning production volumes or expected delivery times.

The characteristics curve relating the cycle time to the daily throughputs can be shifted or stretched into a better position in terms of capacity by focusing on the capacity components or by eventually increasing the number of machines.

5.2 Characteristics Curves Construction

In this section, the characteristics curves of the current fab model are constructed for each technology. Then based on the significant factors found in the factors-screening experiments, more resources were added to the fab one by one and the new characteristic curves were plotted. The addition of new resources was stopped when a total of 5200 wafer starts per week (WSPW) could be produced at no more than 3 times the theoretical cycle time for each technology. Table 3 presents the mixes that were used for each technology in plotting the characteristics curve.

Based on the factor screening experiments performed in Section 5, the following station additions might result in significant improvements in cycle times:

- One Iline Stepper.
- One Duv Stepper.
- One Scrubber.
- One Iline Stepper and one Duv Stepper.
- One Scrubber and one Duv Stepper.
- One Scrubber, one Duv Stepper and one Iline Stepper.

Figures 1-2 present the characteristics curves for each scenario for all the technologies. The y-axis represents the ratio of the cycle time to the theoretical-no-queues cycle time and the x-axis represents the weekly wafer starts for each technology. Note that the total run time for the fab was 300 days after 100 days of warm-up. Each simulation run took from 1 hr to 2 hrs depending on the fab utilization and stability. At each point, five different model replicates were run using different random numbers seeds.

Table 3: Weekly Wafer Starts for each Technology

Technology 1	**Technology 2**
2100	1260
2200	1320
2400	1440
2500	1500
2625	1575
2675	1605
2700	1620
2725	1635
2775	1665
2800	1680
2825	1695
2850	1710
2875	1725
2900	1740
2925	1755
3000	1800
3250	1950

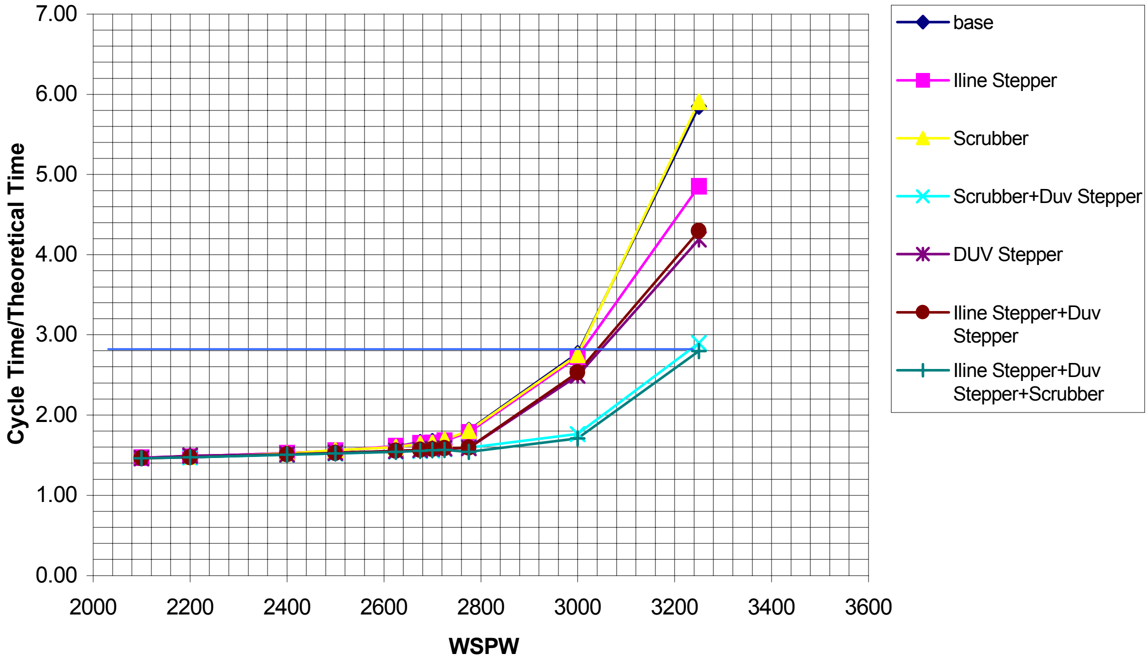

Figure 1: Improvement Scenarios Characteristics Curves for Technology 1

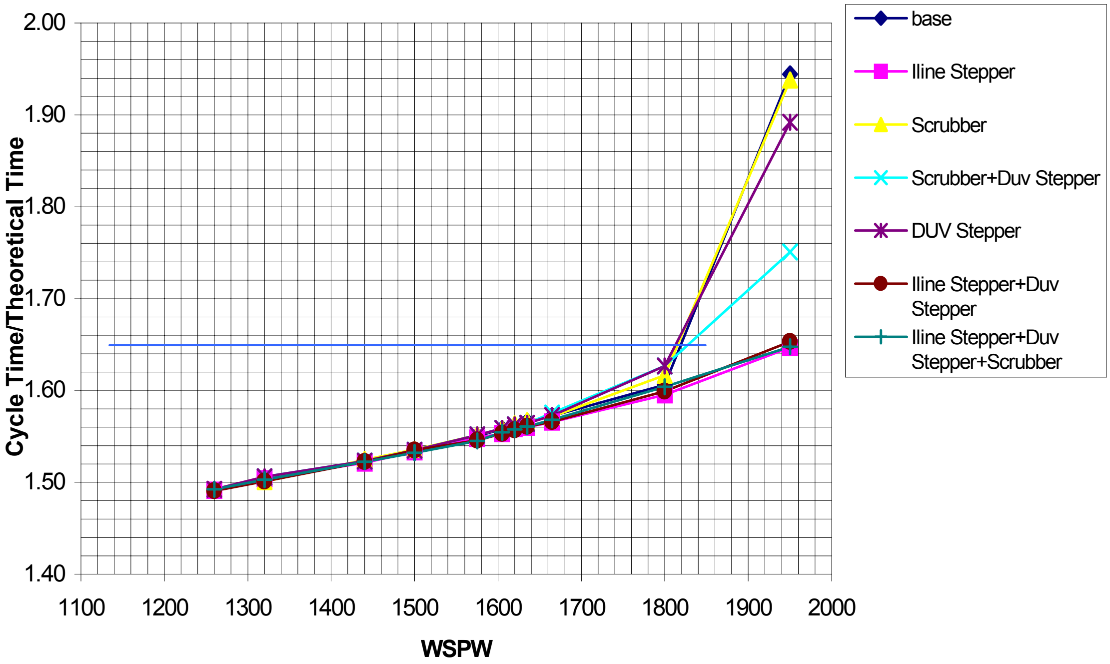

Figure 2: Improvement Scenarios Characteristics Curves for Technology 2

Table 4 is a comparison in production volume capacities for both technologies resulting from each scenario. The comparisons were performed at a certain target cycle time for each technology.

Table 4: Estimated Production Capacities Resulting from each Improvement Scenario

Investment/Scenario	**Technology 1**	**Technology 2**
Target Cycle time to theoretical time ratio	2.8	1.65
Base/Current Fab	3000	1820
Base + Duv Stepper	3040	1820
Base + Iline Stepper	3000	1950
Base + Scrubber	3000	1820
Base + Duv Stepper + Iline Stepper	3040	1950
Base + Duv Stepper + Scrubber	3230	1830
Base + Duv Stepper + Iline Stepper + Scrubber	3240	1950

6 CONCLUSIONS

This research began with the development of a simulation model for the production line of the Agere Systems fab in Orlando, followed by a complete verification and validation for the model. The significant input parameters that influence cycle times for two high-volume major technologies were identified through factor-screening experimental design. Based on these factors, several scenarios involving the addition of tools, aimed at cutting down cycle times, were identified and operating characteristics curves were constructed for each scenario. Bottlenecks were highlighted as production neared the capacity limits. Using the characteristics curves, the differences in production volume capacities among the different scenarios were measured at targeted cycle time for each technology.

7 FUTURE WORK

In this research, the differences in production volumes, among the scenarios, were compared at a target cycle time. Reversing the situation by setting a target production volume, at which reduced cycle times are desired, the benefits of cycle time reduction would be evaluated from a different perspective. Several alternatives can be suggested that will result in reducing the cycle time, while keeping a constant production volume.

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AUTHOR BIOGRAPHIES

DIMA NAZZAL received an M.S. degree in Industrial Engineering from the University of Central Florida. She received a B.S. in Industrial Engineering from the University of Jordan, Amman, Jordan. Her present research interests include simulation modeling and analysis, design of experiments and capacity analysis and planning. She is a member of ASQ. Her email address is `<dnazzal@mail.ucf.edu>`.

MANSOOREH MOLLAGHASEMI is an associate professor of Industrial Engineering and Management Systems at the University of Central Florida. She received her Ph.D. in Industrial Engineering from the University of Louisville in 1991. She also holds a B.S. and an M.S. in Chemical Engineering from the same University. Her research interests involve simulation modeling and analysis, multiple response simulation optimization, and neural networks. She is a member of IIE and INFORMS. Her email address is `<mollagha@mail.ucf.edu>`.