ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING

Factory Modeling and Scheduling for Semiconductor Wafer Fabrication

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INTRODUCTION

This lesson describes computer models and simulators for factory scheduling (logistics), ramp-up and factory floor control. A typical integrated circuit factory is described as multi-process, reentrant and complex. There may be as many as 75,000 wafers in the factory including 300 products and 6,000 masks. The factory may start 10,000 wafers per week and do 200,000 wafer turns per day. Changes in the system such as adding a new piece of equipment or changing photoresist type could completely change the factory performance. These models are tools to assist manufacturing engineers as they manage these factories.

INTRODUCTION (CONT.)

In a wafer fab an operator may see many different lots, products, and processes. At any time there may be a large number of lots to select from to work on. The computer system should display the lot to be worked on next taking into account a variety of lot selection rules, the availability of equipment and operators, the time remaining in the work day compared to the time to complete the process and other factors.

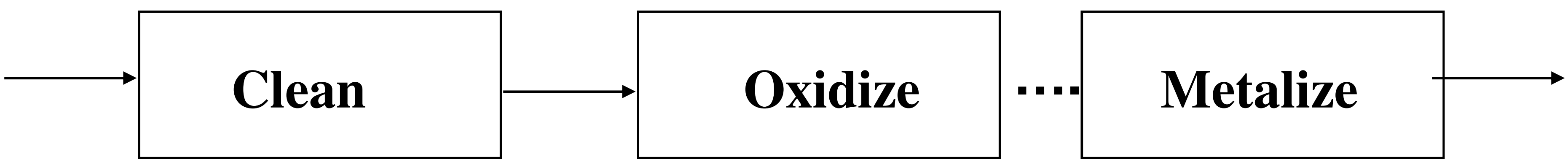
INTRODUCTION (CONT.)

Researchers in the field of microelectronics manufacturing have created computer programs to simulate semiconductor wafer fabrication. They have used these models to study the effect of scheduling on the performance of the manufacturing facility. They have found that scheduling has a significant impact on the performance of semiconductor wafer fabrication, with larger improvements from discretionary input control than from lot sequencing.

TUTORIAL

Since the topic of scheduling is not familiar to most engineers a brief tutorial is presented below:

The manufacturing process is a sequence of operations on the wafer. The number of operations and the sequence may differ from process to process. For example a bipolar process follows a different sequence than a CMOS process.



TUTORIAL - SERVER

Each of these operations is performed by some piece of equipment and the operation is characterized by a mean set up time, a mean process time, a set of times when the machine and operator is available, the number of lots that can be processed simultaneously, etc. The combination of the machine and the queue for that machine is called a server. (The sever performs some service in the context of queueing theory)

Server

Queue
Lots 1,3,5

Oxidize
TS, TP, NLOTS
WHEN

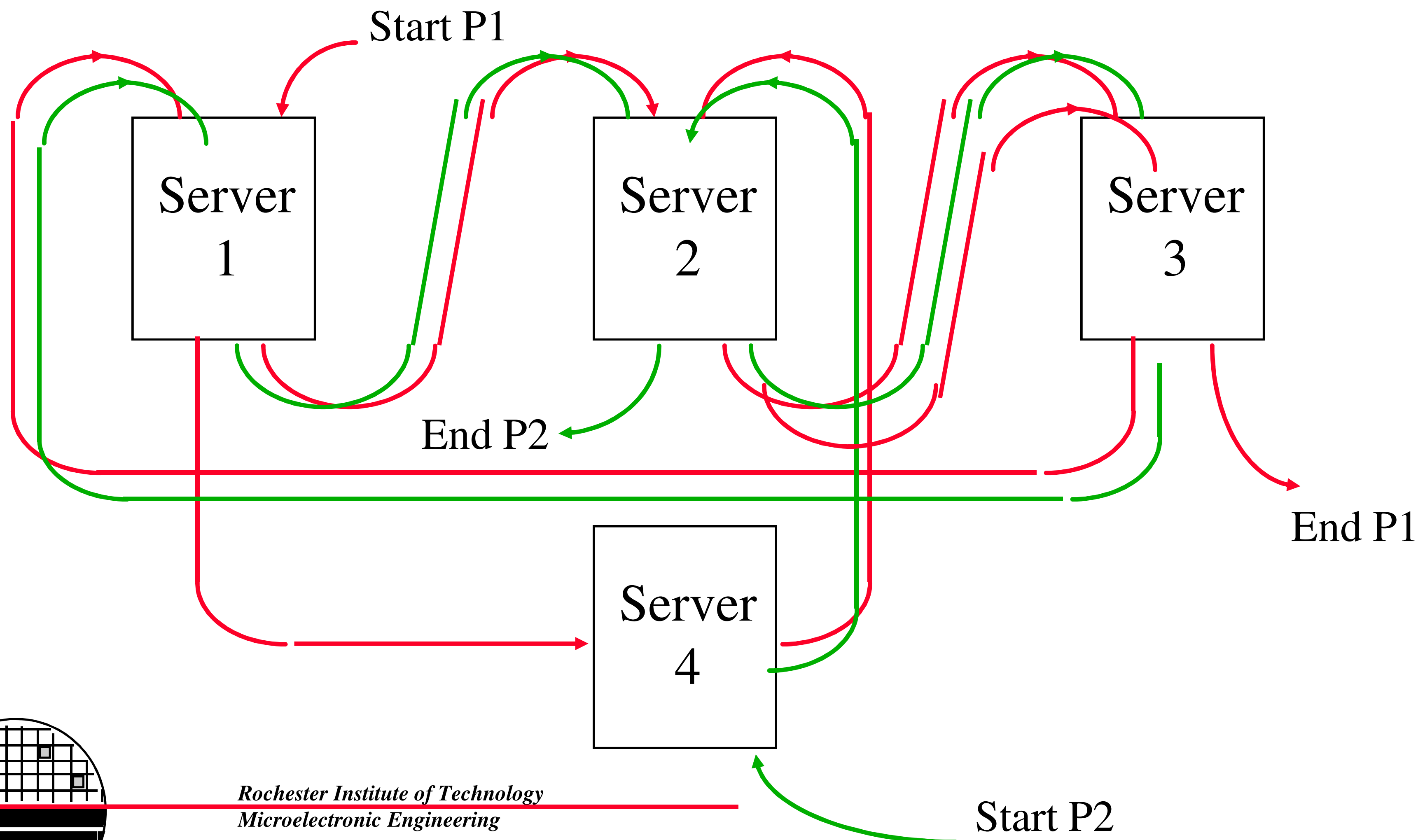
WHEN = times available
NLOTS = # of lots simultaneously
TS = mean set up time
TP = mean process time

TUTORIAL - SERVERS IN A FACTORY

The manufacturing facility consists of a given number of servers

Server 1	Server 2	••••	Server N
Queue **Lots 1,3,5**	**Queue** **Lots 2,6,9**		**Queue** **Lots 4,8**
Oxidize **TS, TP, NLOTS** **WHEN**	**Photo** **TS, TP, NLOTS** **WHEN**		**Etch** **TS, TP, NLOTS** **WHEN**

TUTORIAL - PRODUCTS WITH DIFFERENT FLOWS



TURORIAL - EXAMPLE

The following example is a subset of a typical wafer fabrication process:

Step 1: Server 1 - CL01 - Wafer Clean
Step 2: Server 5 - OX01 - Oxide Growth
Step 3: Server 2 - PH03 - Photolithography
Step 4: Server 4 - ET01 - Etch
Step 5: Server 1 - CL01 - Wafer Clean
Step 6: Server 5 - OX01 - Oxide Growth
Step 7: Server 9 – END

Lets say we have three lots in the factory all following the process above but at different steps in the process at the start of the day.

Lot 1: Step 5
Lot 2: Step 3
Lot 3: Step 1

TUTORIAL - EXAMPLE

Each of the servers need to be defined so that an accurate model can be formulated for each. Mean set up time, mean process time, mean time between failure, mean time to repair, availability, and other parameters need to be defined. For simplicity lets define the mean set up time (TS), mean process time (TP), the availability (AVA) and the number of lots that can be processed simultaneously (NLOTS) for each server. For simplicity set the time increment to 1 hour.

Server 1: CL01 TS=0.5, TP=1.0, NLOTS=2, AVA= 8:00, 10:00, 13:00, 15:00
Server 2: PH03 TS=0.5, TP=2.0, NLOTS=1, AVA=8:00, 13:00
Server 4: ET01 TS=1.0, TP=1.0, NLOTS=2, AVA= 8:00, 10:00, 13:00, 15:00
Server 5: OX01 TS=0.5, TP=1.0, NLOTS=4, AVA= 9:00, 14:00
Server 9: END TS=0.0, TP=0.5, NLOTS=1, AVA= 8:00, 9:00, 10:00, 11:00, 12:00, 13:00, 14:00, 15:00

TUTORIAL - EXAMPLE

Finally, the rules for selecting lots for service by a given server and rules for starting new lots need to be defined. Lets also pick simple rules such as selecting lots closest to the end of the process first and starting new lots when a lot is completed thus keeping the total number of lots in the factory constant.

The simulation will start with a listing of the current status of each lot and each server. Servers will be polled to determine if they are available, servers needed for each lot will be determined, lots to be processed will be selected and will be moved to the next step in the process after the service is completed. The entire process will be repeated for the next time increment and so on until the simulation is complete.

TUTORIAL - EXAMPLE

The simulation table provided below is not filled out. It is left to the reader to complete the table to get a feel for the complexity of the problem:

Time	Server	Availability	Queue			Lot Served			Service
			L1	L2	L3	L1	L2	L3	Pending
8:00	1	1	5		1	5		1	2
8:00	2	1		3			3		3
8:00	4	1							
8:00	5	0							
8:00	9	1							

TUTORIAL - EXAMPLE

Time	Server	Availability	Queue			Lot Served			Service
			L1	L2	L3	L1	L2	L3	Pending
9:00	1	0				5		1	1
9:00	2	0					3		2
9:00	4	0							
9:00	5	1							
9:00	9	1							

Time	Server	Availability	Queue			Lot Served			Service
			L1	L2	L3	L1	L2	L3	Pending
10:00	1	1							
10:00	2	0					3		1
10:00	4	1							
10:00	5	0	6		2				
10:00	9	1							

TUTORIAL - EXAMPLE

Time	Server	Availability	Queue			Lot Served			Service
			L1	L2	L3	L1	L2	L3	Pending
11:00	1	0							
11:00	2	0							
11:00	4	0		4					
11:00	5	0	6		2				
11:00	9	1							

Time	Server	Availability	Queue			Lot Served			Service
			L1	L2	L3	L1	L2	L3	Pending
12:00	1	0							
12:00	2	0							
12:00	4	0		4					
12:00	5	0	6		2				
12:00	9	1							

TUTORIAL - EXAMPLE

Time	Server	Availability	Queue			Lot Served			Service
			L1	L2	L3	L1	L2	L3	Pending
13:00	1	1							
13:00	2	1							
13:00	4	1		4			4		2
13:00	5	0	6		2				
13:00	9	1							

Time	Server	Availability	Queue			Lot Served			Service
			L1	L2	L3	L1	L2	L3	Pending
14:00	1	0							
14:00	2	0							
14:00	4	0					4		1
14:00	5	1	6		2	6		2	2
14:00	9	1							

COMPUTER SIMULATION

A computer program has been written to do the simulation as shown in the example above except that the program can keep track of multiple processes. The number of servers and the number of steps can all be increased to what ever level is desired. The simulation can be set up to start at a given time and continue as long as desired. The simulation is fairly accurate for short simulation times. The rules for selecting lots and input of new lots can also be set up as desired. This computer program has been used for several different examples shown on the following pages.

SIMULATION EXAMPLE

Using the computer program FACTORY.FOR start with lot 1,2,3 at step 14 lot 4 at step 5 and lot 5 at step 1, determine the lot status for 20 days. (note step 20 and 9 is Implant)

								Lot Status at Start of Day													
Lot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Days
1	14	17	19	20	22	23	25	27	30	33	36	40	41	45							15
2	14	16	19	20	20	20	22	23	26	27	30	33	37	40	41	45					17
3	14	16	19	19	20	20	20	20	22	23	23	25	27	30	33	37	40	41	45		20
4	5	8	9	13	16	19	20	20	20	20	22	23	23	26	27	30	33	37	40	41	22
5	1	1	1	1	5	7	9	9	9	9	9	9	14	16	19	19	20	22	23	26	28

Change Implanter to be available at 8:00 and 12:00 instead of at 8:00 only (note step 19 is Photo)

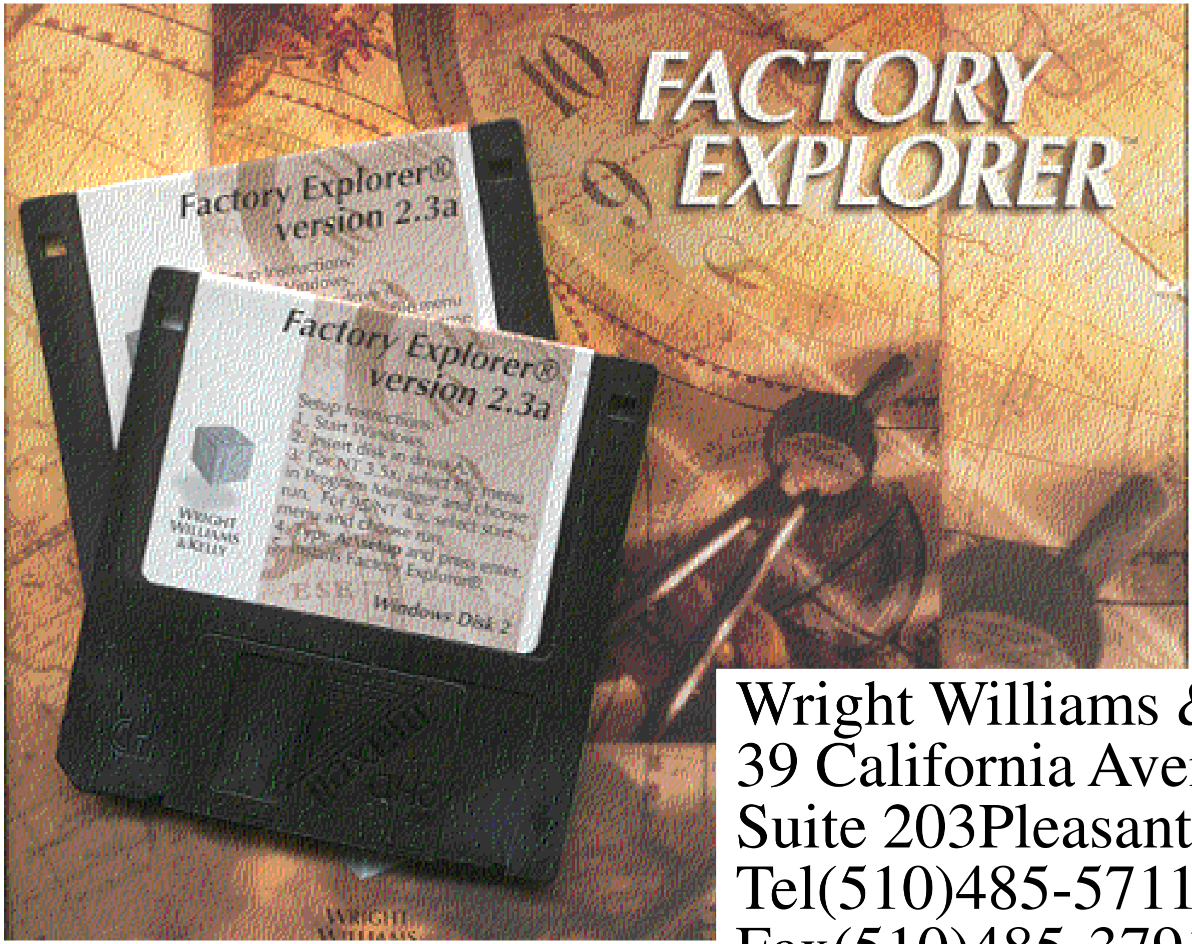
								Lot Status at Start of Day													
Lot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Days
1	14	17	19	22	23	26	27	30	33	37	40	41	45								14
2	14	16	19	20	22	23	26	27	30	33	37	40	41	45							15
3	14	15	19	19	20	22	23	26	27	30	33	37	40	41	45						16
4	5	7	11	15	19	20	22	23	26	26	27	30	33	37	40	41	45				17
5	1	1	1	1	5	5	7	12	16	18	19	19	19	22	23	26	27	30	33	37	24

SIMULATION EXAMPLE

Using the computer program FACTORY.FOR introduce a new lot each day and determine all lot status for 20 days and the total number of days to complete that lot.

Lot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		Days
1	1	5	9	14	18	19	20	22	23	26	27	30	33	37	40	41	45					17
2		1	5	9	14	18	19	20	20	22	23	26	27	30	33	37	40	41	45			18
3			1	5	9	14	18	19	20	20	20	22	23	23	26	27	30	33	37	40		20
4				1	5	9	14	18	19	20	20	20	20	22	23	23	26	27	30	33		21
5					1	5	9	9	9	9	9	9	9	9	9	14	16	19	19	20		26
6						1	5	9	9	9	9	9	9	9	9	9	14	18	19	20		27
7							1	5	9	9	9	9	9	9	9	9	9	14	18	19		29
8								1	5	5	9	9	9	9	9	9	9	9	9	14		30
9									1	1	5	7	9	9	9	9	9	9	9	9		30
10										1	5	5	9	9	9	9	9	9	9	9		36
11											1	5	7	9	9	9	9	9	9	9		37
12												1	5	5	9	9	9	9	9	9		39
13													1	5	5	5	5	7	9	9		40
14														1	5	5	5	5	5	5		40
15															1	5	5	5	5	5		46
16																1	5	5	5	5		47
17																	1	5	5	5		49

FACTORY EXPLORER SIMULATOR



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FACTORY EXPLORER SIMULATOR

Factory Explorer is an integrated capacity, cost, and cycle time analysis tool for manufacturing. Factory Explorer combines an Excel-based user interface with two performance analysis engines. One containing analytic (static) methods and one containing simulation (dynamic) methods. The analytic engine uses a mathematical model to predict system capacity, minimum equipment and staffing requirements, resource usage, bottlenecks, factory gross margin, and product cost. The simulation analysis engine is a fast discrete-event simulation that provides estimates of cycle time, work-in-process levels, and inventory valuation.

FACTORY EXPLORER SIMULATOR

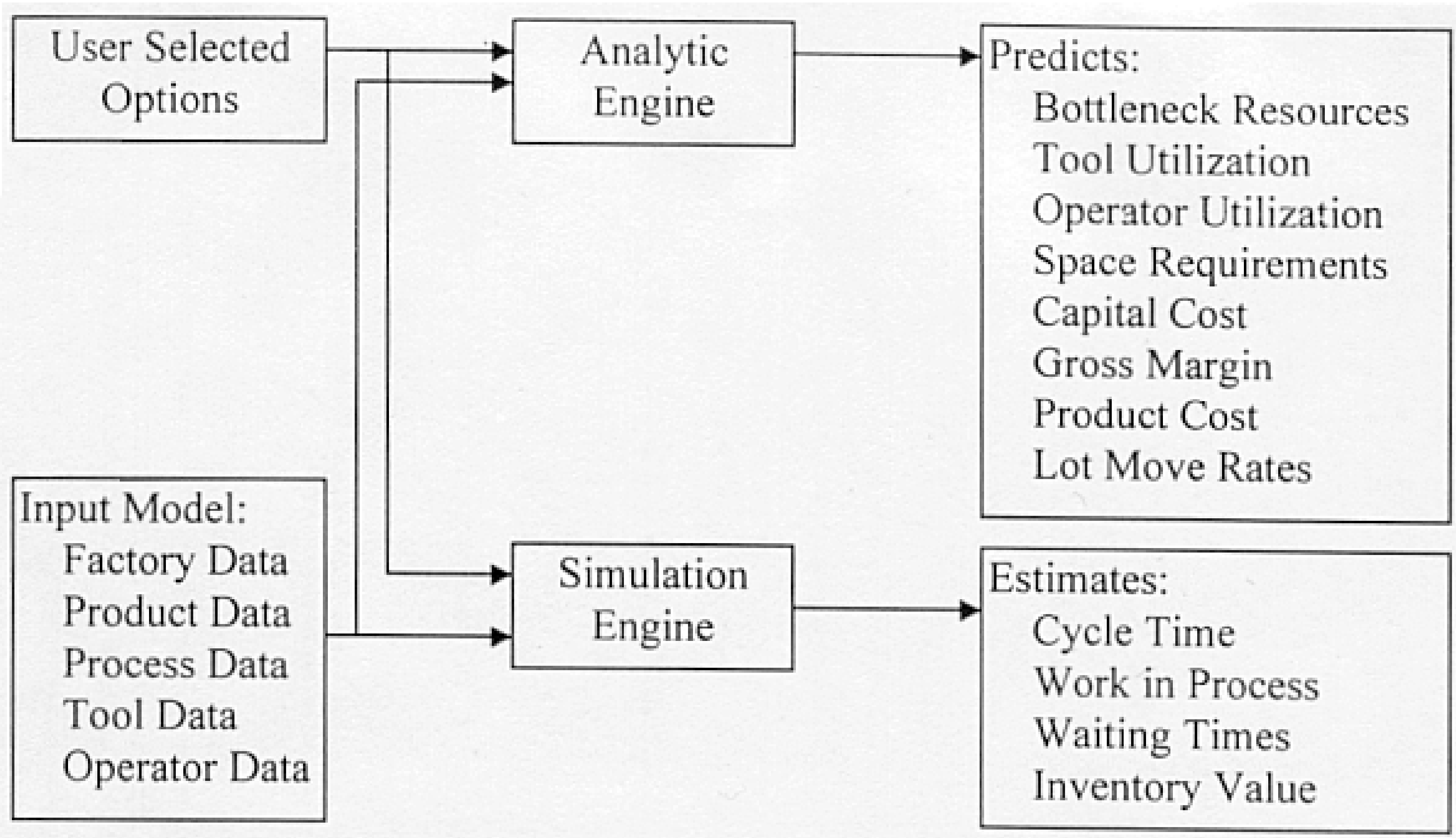

Figure 1-2: Input / Output Diagram: Factory Explorer performance analysis engines.

FACTORY EXPLORER SIMULATOR

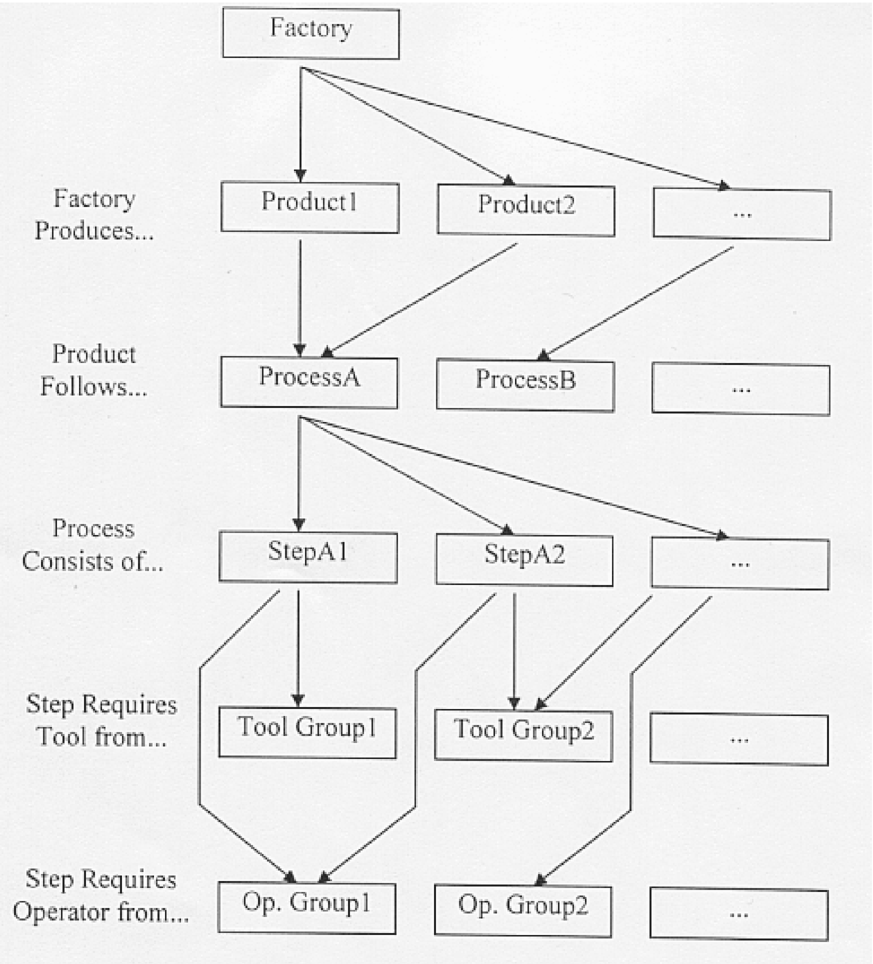

Figure 1-3: Overview of the Factory Explorer object model.

FACTORY EXPLORER DEMONSTRATION

Model Names:

- RITtest – Tutorial Example with 5 Servers
- RITpmos – Simplified PMOS Process
- RITcmos – Full Factory CMOS Process

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3. ManSim/X User's Manual, Tyecin Systems, Inc., Four Main Street, Los Altos, CA 94022, (415) 949-8501.

4. MS/X OnTime User's Manual, Tyecin Systems, Inc., Four Main Street, Los Altos, CA 94022, (415) 949-8501.

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HOMEWORK - FACTORY SIMULATION

1. Set up a model to simulate a factory similar to the that in these notes. Assume the factory contains the following pieces of equipment.

	Ts	Tp	NLots	AVA
Clean	0.5	1.0	2	8,10,13,15
Photo	0.5	2.0	1	8,13
Etch	1.0	1.0	2	8,10,13,15
Oxide	0.5	1.0	4	9,14
End	0	0.5	1	8,9,10,11,12,13,14,15

Assume that we have a process that follows the following sequence:

Step 1: Clean
Step 2: Oxide
Step 3: Photo
Step 4: Etch
Step 5: Clean
Step 6: Oxide
Step 7: End

a) How long will it take one lot to go from Step 1 to the end if no other lots are in the factory?

b) If one lot is started each day what is the status at the end of the 5th day?