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A NEW AMHS TESTBED FOR SEMICONDUCTOR MANUFACTURING

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ABSTRACT

This paper proposes a new dataset of semiconductor fab simulation models. As the size and complexity of FABs increase, it is essential to operate automated material handling systems (AMHS) efficiently. Although the latest testbed, SMT2020 (Semiconductor Manufacturing Testbed2020), is realistic in scale and complexity for modern semiconductor FABs, there is a lack of details on AMHSs. Therefore, we developed details for an AMHS simulation model with sufficient scale and complexity. A full description of the simulation model features is provided, compared with an assumption about transport times in SMT2020. This study aims to provide a test environment for researchers to test operation and logistics in a semiconductor FAB. The prototype of the proposed testbed is open to public use.

1 INTRODUCTION

A semiconductor manufacturing system is currently known to be one of the most complex manufacturing processes (Mönch et al. 2013). The system consists of products that require hundreds of process steps and expensive equipment. Many semiconductor manufacturers use discrete-event simulation as an important decision making tool (Mönch et al. 2013) because the simulations provide real-world like and risk-free experimental environments (Fowler et al. 2015). The manufacturers can experiment with various policies and study long-term phenomena in the FAB. Additionally, it is possible to solve urgent decision-making problems by using simulation models initialized based on the current situation (Fowler et al. 2015; Kopp et al. 2020).

To experiment with decision-making and test policies, practitioners utilize discrete-event simulation with simulation models for FABs in hand. However, because it is challenging to create a sufficiently complex dataset that practitioners can agree on, academic researchers prefer to work on a testbed, whereby the simulation models are publicly available (Kopp et al. 2020). Using a common testbed makes it possible to obtain reproducible results without model-dependency (Hassoun and Kalir 2017).

The most representative standard testbed is the MIMAC testbed published by Fowler and Robinson (1995). It is composed of six wafer FAB models of different complexity. It has been used in various research to study phenomena and design policies for almost 30 years. However, over time, some of the characteristics reflected in the MIMAC testbed have become irrelevant in modern FABs, and several new characteristics have become necessary, such as lot-to-lens dedication, cascading and critical queue times (Hassoun and Kalir 2017).

Hassoun et al. (2019) published the first dataset that reflects the characteristics of the modern FAB. This dataset assumed a situation with a large volume and a low mix. Subsequently, the SMT2020 (Semiconductor

Manufacturing Testbed 2020) was published by Kopp et al. (2020). It consists of four datasets, including situations with a small volume and a high mix. Although the SMT2020 contains the increased complexity and sufficient scale required by modern FABs, Automated Material Handling System (AMHS) details are not included.

AMHS is responsible for transferring wafers in the FAB. Layout and material-handling systems can affect production system performance (Yang and Peters 1998; Brain et al. 1999), and improve product quality by reducing shock and vibration during transfer (Wowk and Billings 1994; Yang and Peters 1998). Studies have been conducted to verify the effect of AMHSs on FAB performance (Tung et al. 2013; Gaxiola et al. 2013; Kim et al. 2016). However, these studies were not conducted on a common dataset that reflects the constraints of the latest FAB. Campbell and Ammenheuser (2000) published a testbed named SEMATECH 300 mm that included an AMHS and operation constraints. However, some features have been outdated, and the model scale is too small to represent a massive FAB with more than 1,000 pieces of equipment and over 2,000 overhead hoist transports (OHT).

Given FAB's high model complexity and complex FAB operation rules, simulation usually separately focuses on production and material handling. However, computational performance is improved, allowing simulations to run concurrently. As Chang et al. (2013) said in his study, the dispatching rule considering AMHS is more effective. Futhermore, decision-making will be possible when using a simulation model that combines production and AMHS.

The objective of this study is to propose a new testbed including information on layout and AMHS for a semiconductor FAB simulation. The testbed is denoted SMAT2022 (for Semiconductor Manufacturing with AMHS Testbed and the expected year of completion and publication). This dataset uses the same base data about processes and operations with SMT2020. As a result, it is possible to generate a simulation model including the following processes: processes of Modern FAB, Layout, and AHMS. The overall process, logistics, and operational logic can be verified through simulation using the data model.

The rest of the paper is organized as follows. Section 2 formulates the components for AMHS in a Semiconductor FAB and includes a discussion on the SMT2020. In Section 3, we describe the SMAT2022 features. Then, in Section 4, we compare the SMAT2022 model with the SMT2020 transportation model. Conclusions and future research directions are presented in Section 5.

2 MAIN COMPONENTS OF AMHS IN A FAB

2.1 Bay Layout

In general, a spine type configuration is used in a semiconductor FAB (Yang and Peters 1998; Castillo and Peters 2004), and therefore we present a FAB with a spine type layout as shown in Figure 1. With this type of layout, a FAB is composed of two types of bays: Intrabay and Interbay. Each bay is laid out as a one-directional loop with passages connecting each bay to the next. An interbay is a center aisle between groups of parallel intrabay, and it can also be a passage that exists on the side. Vehicles move through the interbay to accomplish rapid transport between the intrabays. Occasionally to fulfill large transport requests, a two-tiered interbay can be implemented (Tung et al. 2013).

Previous studies generally used layouts in a separate form of intrabay and interbay (Kim et al. 2016; Campbell and Ammenheuser 2000). The vehicles in an intrabay can only drive in that bay. And there are other vehicles transporting lots between bays inside the interbay. Intrabays are connected through stockers located in the end of the bays. Because this kind of layout causes inefficiencies and bottlenecks in modern FABs, and since the 'Tool to Tool' operation rule is preferred in modern FABs (such as a 'Unified FAB'), this study presents a layout in which intrabay and interbay are directly connected. Tool to tool operation rule means an AMHS operation rule that a lot is sent from a port of one equipment port to a port of the next step equipment, not a stocker and track buffer. The FAB size is assumed according to practitioners' advice. Since there are 1068 facilities in SMT2020 dataset4, the size of a FAB with a similar number of facilities is reflected. As shown in Figure 1, the lengths of interbays and intrabays are set to 360m and 60m, respectively.

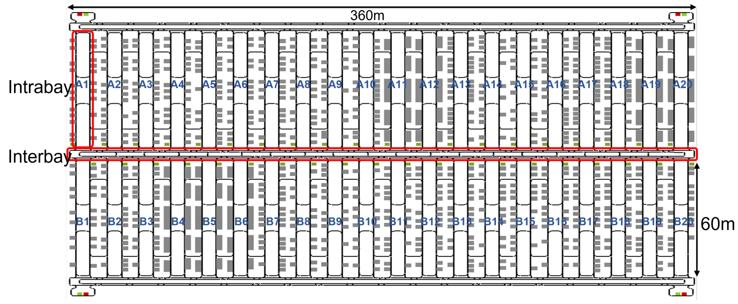

Figure 1: Bay layout.

2.2 Buffers

Because the capacity of each tool group is limited, it is important to design buffer locations in the FAB. Buffers in the FAB preserve lots until the next operation step equipment becomes available. There are two types of buffers in a FAB: a stocker and a track buffer. A stocker is a kind of AS-RS that can store multiple front opening unified pods (FOUP). It is located at the junction of interbays and intrabays. A stocker sometimes performs inter-floor FOUP movement and is utilized as an entry and an exit for lots. However, because it takes a long time to insert and subtract FOUPs from the stocker, nowadays the track buffer is preferred. A track buffer is placed next to or below the track on which OHTs move. It is possible to store one FOUP.

2.3 Vehicles

The AMHS is responsible for transporting wafers between process equipment. Wafers are generally grouped in lots of 25 wafers and sealed in carriers called FOUP to prevent contamination. The AMHSs used in FABs include automated guided vehicle (AGV), rail guided vehicle (RGV), overhead hoist transport (OHT), and continuous flow transport (CFT).

Because the OHT system is the most commonly used AMHS in modern FABs, we introduce more details about OHT. The OHT is a vehicle that travels under the overhead tracks and directly accesses a load port of a stocker or process equipment. Each vehicle has a capacity of one FOUP. To reflect applicable OHT specifications for a 300 mm modern FAB, we cited data presented by 'S' company in Korea. The specifications of the vehicles in the dataset are summarized in Table 1.

Table 1: OHT specification.

Category	Specification
Stright Speed	$5.0m/s$
Curve Speed	$1.0m/s$
Acceleration	$2.0m/s^2$
Deceleration	$3.5m/s^2$

3 DATA MODEL CHARACTERISTICS

In this section, we describe the SMAT2022 simulation model. The SMAT2022 consists of eight tables, excluding the SMT2020. The model will be provided in excel format at https://github.com/kwoo-lee/SMAT2022, and additional details are summarized in a file titled "Instruction for AMHS.pdf". Since the details of the process and operation were used in the SMT2020, our dataset simply consists of the following eight tables: ‘TrackNode’, ‘TrackLink’, ’Bay’, ‘Equipment’, ‘Station’, ‘Vehicle Type’, ‘Vehicle’, and ‘ACID’.

3.1 Layout Modeling

The layout information for FAB is defined in the following three tables: ’TrackNode’, ’TrackLink’, and ’Bay’. Since a track traveled by OHTs can be expressed using a directional graph, we considered the track as a set of nodes and links. In the ’TrackNode’ table, each node is represented by three-dimensional coordinates. The ’TrackLink’ table has information on the fromnode and tonode that each link connects to and the maximum speed that an OHT can drive. Because an OHT has different driving specifications on straight and curved tracks, information on the appearance of the track link is required (straight or curved). The ’Bay’ table contains each bay’s name, type, and reticle. The reticle indicates where the lithography equipment belongs. Shortcuts were placed in the middle of the intrabay to make OHTs drive efficiently. Additionally, the interbay was configured in a two-tiered form.

3.2 Equipment Modeling

The SMT2020 dataset contains eight process types, such as diffusion, lithography, and three types of metrology. There are 105 tool groups consisting of 1068 equipment. The equipment types are classified into ‘Table’, ‘Cascading’, and ‘Batch’ types. Each equipment dispatches based on the dispatching rule defined for each toolgroup in SMT2020, stops according to scheduled and unscheduled downtime and identifies setup time to process the next type of lot according to the setup rule. The size of each facility is assumed based on the equipment size provided by company S, and all equipment is assumed to be the same size. And assigning toolgroup to the bay is a fundamental issue in the semiconductor FAB design stage. Equipment belonging to the same tool group is placed in the same intrabay or set of intrabays (Yang and Peters 1998; Campbell and Ammenheuser 2000). Each toolgroup is assigned to a bay with the following assumptions in this testbed. Diffusion and lithography, the representative bottleneck processes of semiconductor FAB, were placed in the intrabays in the center, and the remaining toolgroups are located in order. It is expected that experiments can be conducted by modifying this dataset in the future and finding a better layout.

The ’Station’ table represents the types of ports in the FAB (i.e., equipment ports, stocker ports, and track buffers). Each station has a position with a link and an offset (not a three-dimensional coordinate) where OHT arrives and works. It is defined by station type and In/Out type. Some ports can only interact one way to load or unload FOUP, whereas others can interact in both directions.

3.3 Vehicle Modeling

The information on vehicles in a FAB is defined in the following two tables: ’Vehicle Type’ and ’Vehicle’. The ’VehicleType’ table contains vehicle specifications such as vehicle size, maximum speed, acceleration, deceleration, and minimum distance between vehicles. We defined an OHT specification as mentioned in Section 2. The ’Vehicle’ table describes the vehicle name, type, and initial location. Because a vehicle travels along a track, the vehicle’s initial location is represented by TrackLink and offset on that link. To satisfy the scale and complexity of the huge FAB presented in SMT2020, we placed 500 OHTs in our dataset. In the future, an optimal number of OHTs may be determined by simulation.

3.4 Product Modeling

Two types of products in datasets 1 and 3 and ten types of products in datasets 2 and 4 are defined. Datasets 3 and 4 include engineering lots. Each lot is prioritized into ‘regular’, ‘hot’, ‘super hot’, ‘engineering’, and ‘engineering hot’. Lots are released according to the schedule in SMT2020. Depending on the product type, 242 to 583 process steps are performed. In this process, the critical queue time (CQT) between the steps must be satisfied.

4 PERFORMANCE COMPARISON WITH SMT2020

The simulations were conducted over two years. The first year was not considered as it represented the warm-up period. Each simulation took 84 hours to run in the following computer environment: (CPU: i9-12900k, ram: 32GB ddr5, GPU: rtx3080ti). The simulation was repeated five times independently for dataset 4 (Low-Volume, High-Mix). For simulation experiments, we used commercial software Pinokio developed by Carlo, Republic of Korea. As performance measures to compare datasets, we used transport time and a Tool-to-Tool (T2T) ratio, the ratio of transfers from equipment to equipment among all deliveries.

4.1 General Performance

An overview of simulation results and general performance measures of each functional area of SMAT2022 is presented in Table 2 and Table 3. Availability is the relative proportion that excludes the time the equipment is out of service and maintenance work. And the utilization rate is the ratio of the time the facilities in each area were utilized. We excluded the 'Delay_32' area of SMT2020 because we modeled the buffer system like track buffer and stocker separately.

Table 2: Simulation results of dataset 4.

Product / Type		Throughput (lots)	Average cycle time (days)	Lots on time
Production Lot	Regular Lot	18318	35.62	99.43%
	Hot Lot	504	28.58	98.21%
Engineering Lot	Engieering Lot	2945	44.67	99.73%
	Engineering Hot Lot	756	35.58	38.23%

Table 3: General performance measures of dataset 4.

	Population (Count)		General Performance	
Area	Toolgroups	Tools	Utilization	Availability
Dielectric	10	67	71.45%	90.42%
Diffusion	10	75	85.27%	93.14%
Dry Etch	21	393	80.71%	92.84%
Implant	9	36	82.64%	91.03%
Lithography	11	188	83.45%	91.72%
Planarization	6	33	81.70%	86.85%
ThinFilm	11	93	76.95%	91.81%
Wet Etch	14	104	86.08%	93.32%
Defectivity Metrology	7	17	69.89%	96.73%
Litho Metrology	4	57	86.27%	96.64%
Thin Films Metrology	2	5	60.27%	96.71%
Total	105	1068		

4.2 Transport Time

In SMT2020, products must pass 242 to 583 steps depending on product type. First, they are processed with specific equipment for a step and then moved to the next step. Kopp et al. (2020) described transport time modeling as uniformly distributed between five and ten minutes. However, described transport time modeling as uniformly distributed between five and ten minutes. However, the average was 71.31 seconds in a simulation that included a layout, vehicles, and stations.

Detailed transport times are shown in Table 4. Bay Distance is the abbreviated distance between bays. It means the number of other bays between two particular bays. For example, when an OHT moves a lot in intrabay A1, the bay distance is 0; when an OHT moves a lot from intrabay A1 to A3, the bay distance is 2. A raw transportation time means when other OHTs did not block OHT, and waiting time means time stopped by other OHTs.

Transport time can be different depending on the layout and AMHS operation rule. Based on the layout, different results are generated depending on factors such as the bay assignment of toolgroups, the number of bay shortcuts, the number of interbay tiers, and the presence or absence of upper and lower interbays. Based on AMHS operation rule optimization, transport time can be shortened according to rules such as appropriate OHT allocation for specific logistics requests and proper idle OHT retention by the bay.

Table 4: Transport time.

BayCount	Transport Time (sec)	Raw Transport Time (sec)	Waiting Time (sec)
0	42.61	35.71	6.9
1	76.17	68.14	8.03
2	110.41	99.85	10.56
3	115.82	104.25	11.57
4	114.48	103.98	10.5
5	141.44	127.94	13.5
6	159.32	146.2	13.12
7	159.34	145.23	14.11
8	162.74	147.44	15.3
9	169.62	154.99	14.63
10+	209.75	187.0	22.75

4.3 T2T(Tool-to-Tool) Ratio

To estimate the efficiency of operations in a FAB, practitioners use the T2T ratio. It is the ratio of the direct delivery from one tool to another to total movements. Figure 2 shows three types of lot transportation of OHT, including 'tool to tool', 'tool to buffer', and 'buffer to tool'. Because the capacity of a toolgroup is limited, a large amount of lots is usually moved to buffers before when they move to the next step. A higher T2T ratio means a lower transportation volume and storage requirement. The T2T ratio is calculated as the ratio of tool to tool movement among the total movement amount. Since a lower T2T ratio means more buffer space and transport requests, it is desirable to increase the T2T ratio to reduce the cycle time and the cost. As a result of the simulations, the average T2T ratio is 60% for SMAT2022. On the other hand, the T2T ratio is always 100% because there is no buffer.

5 DISCUSSION

In this paper, we present a new testbed that expands on the SMT2020. It includes overall information on an AMHS and a layout. The model will be provided in excel format at https://github.com/kwoo-lee/SMAT2022, and will include a user guide/manual for the model. We used the AMHS model to show the differences compared to the SMT2020 transportation model.

The simulation results demonstrated that, including AMHS, most transports were finished before three minutes compared with SMT2020 (presented as uniformly distributed between five and ten minutes).

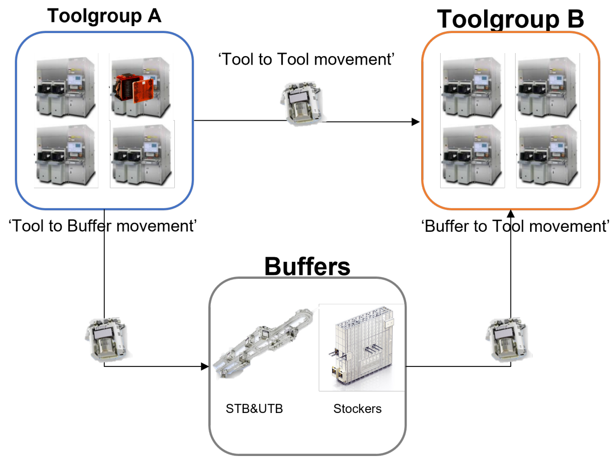

Figure 2: Transportation types.

Furthermore, since the lot is transferred to a buffer when target equipment is busy, the T2T ratio is approximately 60% on average.

Using this testbed, researchers can not only experiment with the operating policies of an AMHS, such as OHT dispatching, drop location, and routing, but also evaluate the desired layout by modifying and expanding the data scheme. The next version of the testbed will be presented within a year, including the four situations presented in SMT2020 and a higher logistics complexity, such as inter-floor and inter-building transportation.

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