Chapter 86
A Novel Vehicle Pre-dispatching Method for Automated Material Handling System in Semiconductor Manufacturing

James T. Lin and Chih-Wei Huang

Abstract As the demand for ultra-clean areas in semiconductor fabrication has increased, the need for more efficient automated material handling system (AMHS) has become imperative. A diffusion tool is characterized by its long processing time of 6–12 h, thus making it a form-batch manufacturing step. Out of necessity with this application, wafer lots are temporarily stored in stocker and are delivered to diffusion tools for processing when the Work-In-Process (WIP) level reaches 4–6 lots. As a result, diffusion tools wait for long wafer delivery time due to the current vehicle assignment method, thus greatly impacting transportation and production efficiency.

In order to improve the transport performance, a novel vehicle assignment method is proposed. Unlike the current methods, which assign idle vehicles to move to load ports sequentially, the novel vehicle pre-dispatching method calls several idle vehicles to move to a load port to simultaneously execute transport jobs with the goal of shortening a vehicle's arrival time. To aid in our research, we performed simulation analysis of an AMHS for a diffusion area. The simulation outcome indicates that a substantial improvement in AMHS transport performance is achieved with applying of the vehicle pre-dispatching method.

Keywords AMHS • Diffusion • Vehicle assignment • Simulation

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R. Dou (ed.), *Proceedings of 2012 3rd International Asia Conference on Industrial Engineering and Management Innovation(IEMI2012)*,
DOI 10.1007/978-3-642-33012-4_86,

Introduction

In semiconductor manufacturing, the wafer travels approximately 10 miles within the fab during the entire processing and typically the wafer visits over 250 processing tools to undergo several hundred individual processing steps (Agrawal and Heragu 2006). Wafer movement occurs between and within different processing area, such as *photo*, *thin-film*, *etching*, and *diffusion*. More specifically, because of characteristics of highly re-entrant processing and larger wafer dimensions, the complexity of material handling and control required by a semiconductor manufacturer has been extensively increasing recently. Over the years with the rapid development of control technology, full-fab automation has become reality in a 300 mm wafer fab. An automated material handling system (AMHS) is a useful solution to fab automation, which is capable of optimizing productivity, improving tool utilization and ergonomics, and reducing particle contamination and vibration shocks to wafers. A typical AMHS consists of track systems, transport vehicles, stocker systems, and a material control system (MCS). Front-opening unified pod (FOUP) with a carrying capacity of 25 wafers is used to transport wafers in a 300 mm wafer fab. These 25 wafers form a manufacturing batch size, called a wafer lot, to be processed in the tool and stored in the stocker. The MCS is a software system used to control vehicle routing and dispatching; it is also used for transport job control of the material and plays an important role in receiving transport jobs from the manufacturing execution system (MES).

In a wafer fab, each wafer lot follows its specific processing steps to be processed in the different tools. Each wafer lot is sequentially moved from the preceding tool to the succeeding one. To complete a wafer lot movement, the MCS has to generate a transport job in the AMHS system. Hence, a transport job is a MCS software command that moves the wafer lot from a source to a destination node. With the analysis of MCS database, the transport jobs demand of each processing area is different. Figure 86.1 shows the transport jobs demand of the diffusion and non-diffusion area. The transport jobs in the diffusion area are 4 jobs in average, with minimum 0 and maximum 15. The transports jobs in the non-diffusion area are 3 jobs in average, with minimum 0 and maximum 7. To compare the difference for these two areas, the variation in the diffusion is higher than the other one. This high variation result in the diffusion area is caused by diffusion tool *form-batch manufacturing* step. The tool requires 4–6 vehicles to transport wafer lots to the tool within a limited time. As an example shown in Fig. 86.2, there are three furnace tools in a diffusion bay. When the tool-A reaches to 6 lots WIP level at time T_5, the MCS generates 6 transport jobs to move these lots to the load port in the tool-A. The AMHS has to assign 6 vehicles to serve these transport demand from stockers to tools. In a practical production fab, many transport jobs in the load ports of a stocker wait for the AMHS vehicle service with a limited time. When vehicles quickly move wafer lots to a furnace tool, the manufacturing system can produce more wafer lots and can minimize tool idle time. Therefore, it is important to manage vehicles assignment and dispatching control to achieve the desired performance measures and costs to procure an optimized AMHS, and much literature is dedicated to this aspect of AMHS.

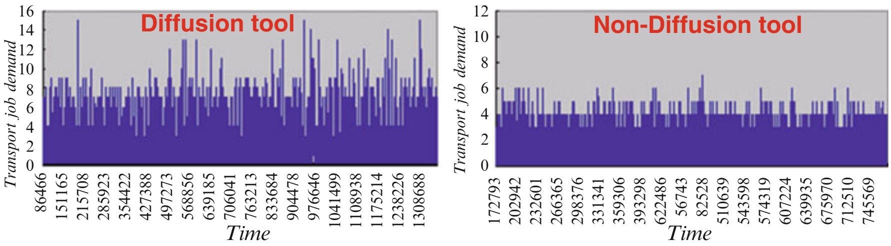


Fig. 86.1 Transport job demand of the diffusion and non-diffusion area

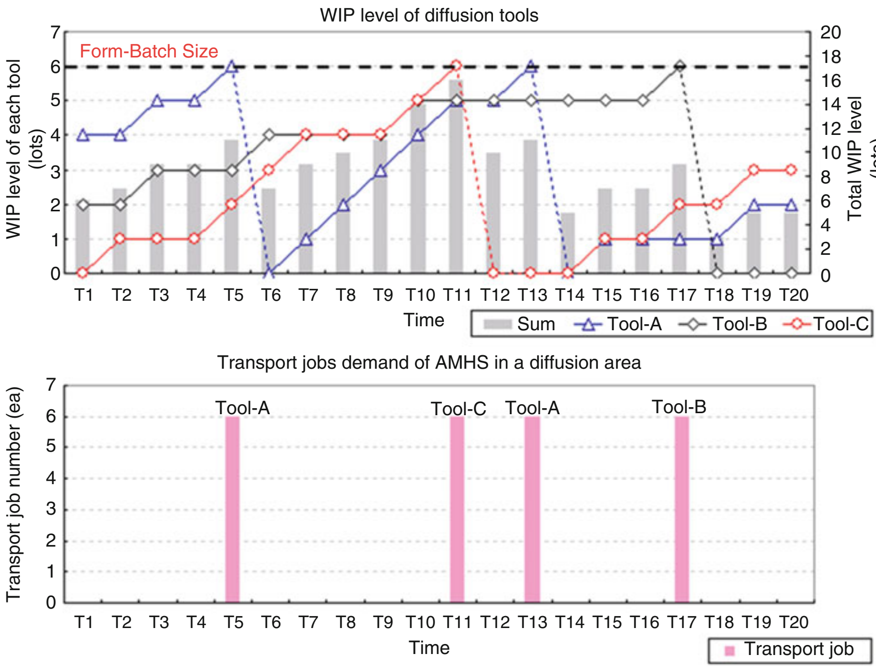


Fig. 86.2 An example of transport job demand analysis in a diffusion area

The AMHS vehicle management problem in these literatures can be categorized into three categories: *vehicle fleet size*, *vehicle dispatching rule*, and *vehicle routing decision*. The vehicle fleet size problem is to determine the minimum number of vehicles required to transport wafer lots in the factory. Maxwell and Muckstadt (1982) formulated the automated guided vehicle (AGV) transport problem into a mathematical model with an objective to minimize the total travelling times of idle vehicles. Their approach found the minimum number of vehicles needed to satisfy a specific demand requirement. The objectives using dispatching rules to control vehicles are minimizing vehicle waiting time and maximizing system throughput. Egbelu and Tanchoco (1984) firstly proposed the AGV vehicle dispatching problems in two aspects: workcenter-initiated versus vehicle-initiated task-assignment problems. Better performances are shown on simulation results on the combination of the modified first-come, first-served (FCFS) rule with the nearest vehicle (NV) or longest idle vehicle (LIV) rules. Lin et al. (2001) presented their performance evaluation of a double loop interbay AMHS, considering the effects of the dispatching rules. The results showed that the combination of the shortest distance with the nearest vehicle (SD-NV) and the foremost-encounter-first-served (FEFS) rule outperform the other rules. The vehicle routing decision problem decides the route a vehicle should take and the sequence of jobs that this vehicle should visit. The objective of the routing of vehicles is to minimize transport time of wafer lots. Kim and Tanchoco (1991) proposed an algorithm based on Dijkstra's shortest-path method to schedule vehicles based on the nodes' time windows. Baker and Ayechew (2003) applied a generic algorithm to solve basic vehicle routing problems and obtained solutions up 0.5% above best known results on average. Renaud et al. (1996) applied meta-heuristics, tabu search, that have been successfully implemented by other researchers in vehicle routing and were reported to perform very well.

As connecting the interbay and intrabay tracks to reduce transport time through stockers, vehicle types and vehicle allocation control in the connecting transport AMHS are widely studied to optimize overall transport performance. Lin et al. (2003) firstly proposed four types of vehicle (A, B, C, and D) to perform the connecting transport tasks by three combinations (A–B, A–C, and A–D) of vehicles. The minimum number of vehicle types was calculated using a simple procedure followed by calculating delivery quantity for all vehicle types. To improve the waiting time of fixed vehicle type proposed in Lin et al. (2003), Lin et al. (2004) continuously proposed a new concept of virtual vehicle to change vehicle type dynamically. Simulation results showed the virtual vehicles outperformed wafer throughput, transport time and waiting time than the fixed vehicle. To avoid congestion or idle time in the intrabay system, Lin et al. (2005) proposed the control of the upper limit or the lower limit on the number of vehicles in the intrabay. Their results indicated that this control significantly affects the travel time, the waiting time and the idle vehicle utilization.

In order to improve the transport performance for a diffusion bay, the concept of a vehicle pre-dispatching method is proposed to solve the high idle vehicles demand with a short time. The objective of this method is to assign idle vehicles at the same time to reducing the vehicle waiting time for each transport job in a diffusion area. Compared with current industry practices, our approach significantly reduces the wafer lots' waiting vehicle time as proven in a simulation study.

Methodology

There are three major tool types located in the diffusion area. These tools include furnaces, cleaners, and metrology tools. In integrated circuit manufacturing process, the diffusion process is characterized by high-temperatures and long-processing time.

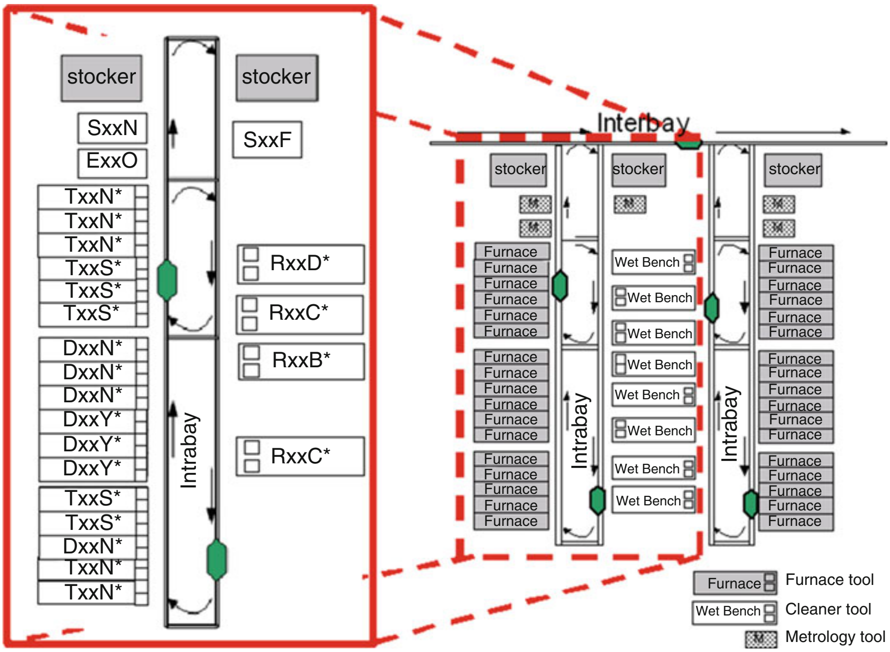


Fig. 86.3 An exemplary layout of a diffusion area

The process flow of a diffusion area includes wafer-cleaning, wafer-oxidizing, and wafer-measuring three steps. Firstly, wafers are processed in the cleaner tools to remove particles, metal ions, organics, and native oxides on the wafers to improve wafer quality. The cleaned wafers are processed in the furnace tools to produce an oxidation or nitride film on the wafer surface. Finally, the wafers are measured in the metrology tools to ensure a satisfactory thickness and uniformity required for the oxidation or nitride film. Figure 86.3 depicts an exemplary layout of a diffusion area in a 300 mm wafer fab that contains 34 furnace tools, 8 cleaner tools, 5 metrology tools, 2 single loop intrabay systems, 3 stockers, multiple shortcuts, and multiple bypasses. The vehicle used is overhead hoist transporter (OHT), which holds the FOUP by its top flange. The vehicle can directly move the wafer lot from one process area to the other area by the interbay and intrabay track system. The information of these tools in this diffusion area is shown in Table 86.1.

The characteristic of a long processing time then arises with furnace tools which are designed to batch-process 4–6 wafer lots to maximize tool throughput at the same processing time. A *form-batch* operation as illustrated in Fig. 86.4 is widely adopted by diffusion tools. Form-batch operation collects the WIP of the furnace tool in the stocker shelf and prohibits wafer lots from being transported to the furnace tool until the WIP level reaches a predetermined size. As shown in Fig. 86.4 status (2) and (3), when Furnace A's WIP reaches to 4 lots, the system calls AMHS vehicles to move these wafer lots from stocker to tool to complete a form-batch operation.

Table 86.1 The tools information in the diffusion area

Tool group	Type	Max. batch size	Load port quantity	Buffer size	Tool quantity	Lot process time (s)	Throughput rate (pcs/h)
Wet bench	RxxB	2	2	x	1	900	100
	RxxC	2	2	x	2	900	100
	RxxD	2	2	x	2	900	100
Furnace	TxxN*	6	2	18	5	27,000	20
	TxxS*	6	2	18	5	30,000	18
	DxxN*	6	2	18	4	36,000	15
	DxxY*	6	2	18	3	27,000	20
Metrology	ExxO	1	2	x	1	360	250
	SxxF	1	2	x	1	1,059	85
	SxxN	1	2	x	1	600	150

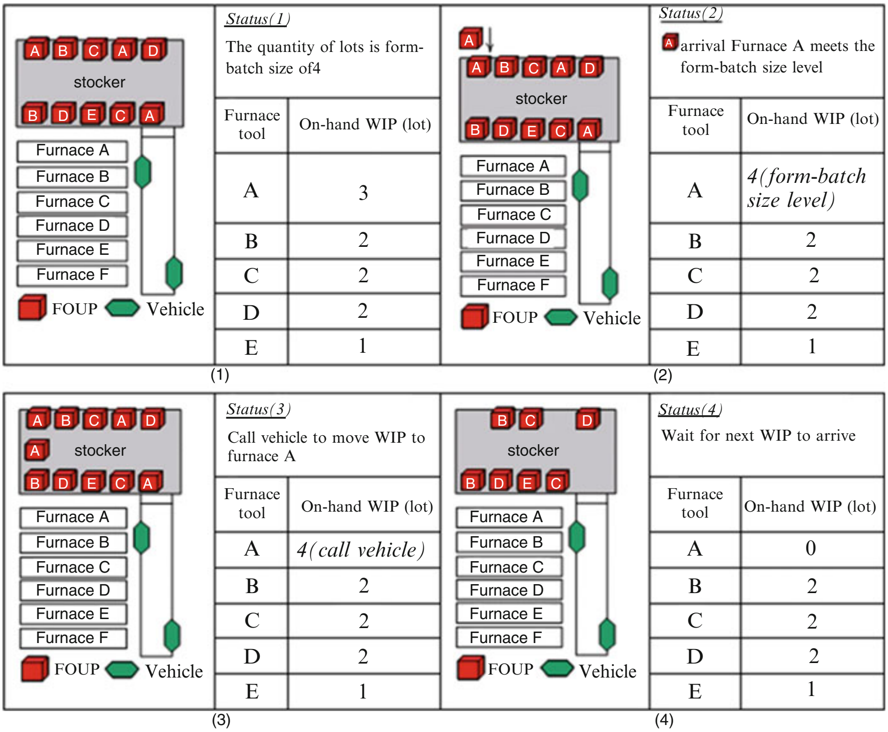


Fig. 86.4 Form-batch manufacturing

In a typical AMHS system, a transport job is triggered either by stockers or tools and then the MCS assigns an idle vehicle, which is selected by the predetermined vehicle dispatching rule, to move the wafer lot from the source to the destination station. With this current vehicle assignment method to generate the transport jobs for stockers or furnace tools, all of transport jobs, which are created from the same

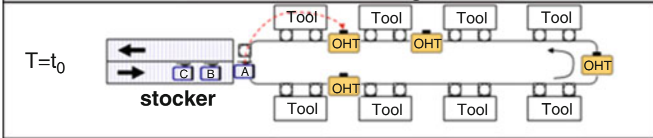
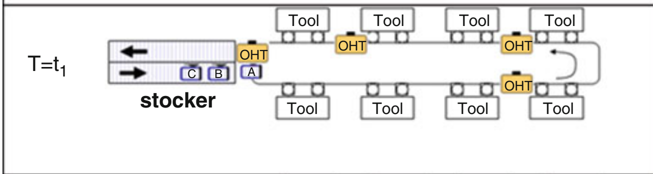
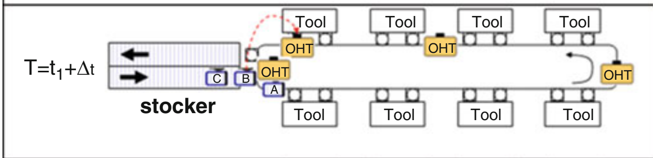
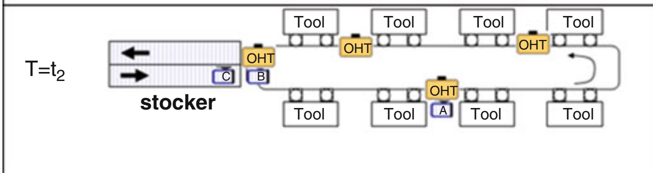
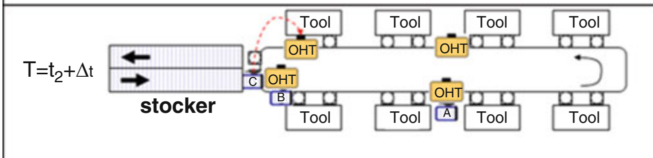
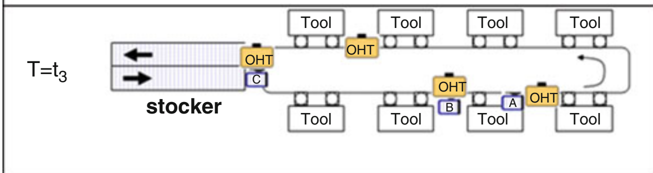
Material Flow Diagram	State
	(1) Lot-A is assigned a nearest OHT at t_0
	(2) After the OHT loading Lot-A, Lot-B is moved to output port at t_1
	(3) Lot-B is assigned a nearest OHT at $t_1 + \Delta t$
	(4) After the OHT loading Lot-B,Lot-C is moved to output port at t_2
	(3) Lot-C is assigned a nearest OHT at $t_2 + \Delta t$
	(6) After the OHT loading Lot-C, all lots finish OHT assignment at t_3

Fig. 86.5 Vehicle assignment by the current method

stations, will be sequentially performed one by one. As shown in Fig. 86.5, there are three wafer lots waiting for vehicles to move from a stocker output port to tools. The MCS assigns an idle vehicle to move the first wafer lot (Lot-A) from a stocker to a tool. After the vehicle finishes the Lot-A movement, the MCS continues to assign an idle vehicle to move the second wafer lot (Lot-B). Finally, the MCS assigns an idle vehicle to move the third wafer lot (Lot-C) after Lot-B is moved out from a stocker to a tool. This one by one vehicle assignment method is designed by each load port of stocker or tool only allowed sending one command to the MCS at one time. However, the transport performance by this current vehicle assignment method is solely determined by waiting for an idle vehicle to arrive. In particular, the form-batch operation of furnace tools requires the AMHS system to transport

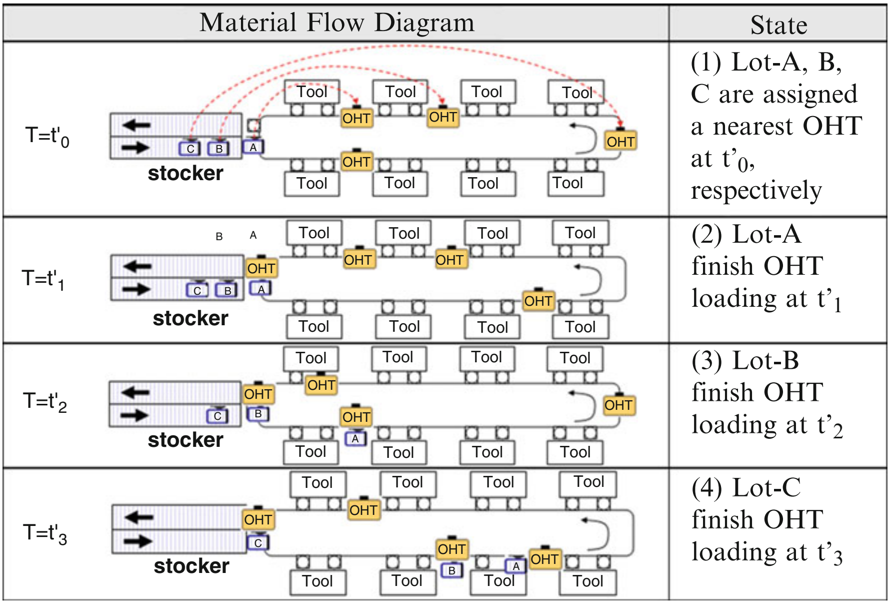


Fig. 86.6 Vehicle assignment by the PDVA method

4–6 jobs within a limited time. With the use of sequential vehicle assignment method, much of the time is spent waiting for idle vehicle's arrival. Hence, a novel vehicle assignment method, named Pre-Dispatching Vehicle Assignment (PDVA), is proposed to improve the above-described phenomenon.

The objective of the PDVA method is to reduce the vehicle waiting time for each transport job in a furnace tool or a stocker. In this proposed method, several idle vehicles are assigned to simultaneously execute transport jobs for the same stations. Figure 86.6 briefly demonstrates the detail behavior by the PDVA method. When there are three wafer lots waiting for vehicles to move from a stocker output port to tools, the MCS assigns three idle vehicles at a time to move these lots simultaneously. After the first wafer lot (Lot-A) is moved out by a vehicle, the second wafer lot (Lot-B) waits for the next vehicle arrival without assigning a vehicle again. Therefore, these three wafers take one time to assign vehicles and these assigned vehicles move to the same station to reduce the vehicle waiting time of these lots.

Features of the PDVA method are presented as follows.

(A) Application scope: Two transport scenarios can be performed by the PDVA method. One is a transport request from the internal buffer to the load port in a furnace tool and the other one is a form-batch operation from a stocker to a furnace tool.

(B) Modification of the current vehicle assignment rule: The PDVA method is a new vehicle assignment strategy based on existing dispatching rules. In the current paper, the vehicle dispatching rule uses the combination of SD–NV (shortest distance and nearest vehicle) and FEFS (the foremost-encounter-first-served) rule. Being based on the existing lot or vehicle dispatching rules, it only replaces the original one by one vehicle assignment method to assigning idle vehicles for the same station at a time.

(C) Determination of a reasonable amount of assigning vehicles: It is essential that a number of vehicles assignments at a time be controlled. Too many assignment vehicles can cause traffic congestion, while too few assignment vehicles can lead to long vehicle arrival time.

Some characteristics of this PDVA method are identified such as an improvement in vehicle arrival time, a reduction in lot waiting time for transport, a reduction in the diffusion tool idle time, and new roles for vehicle dispatching. In general, the load port of a diffusion tool or a stocker can only request a vehicle to transport the wafer lot. If the PDVA mechanism occurs in the load ports, then the wafer lots in these load ports can request several vehicles to a source station at the same time. Thus, the new role for the load ports is better than the sequential method. Hence, the lot waiting time for vehicle's arrival is reduced.

Results

The simulation is the most widely used tool in analyzing AMHS. A simulation experiment was performed by Campbell et al. (2000) to compare effects on cycle time, WIP, and tool utilization due to various factors (e.g., AMHS equipment downtime, number of stockers, etc.). Pierce and Stafford (1994) and Cardarelli and Marcello (1995) developed simulation tools to analyze the AMHS system performance. Their emphasis was on estimating the WIP stocker capacities to provide a smooth operative environment and clean room material handling.

In the current paper, a discrete-event simulation model is used to evaluate the transport performance of an AMHS system for a diffusion area with the PDVA method. The model is built and executed with the *eM-Plant* simulation package. The *eM-Plant* is an object-oriented simulation software with several merits, including hierarchy, inheritance, and concurrent simulation. Basic objects are enabled in the software for immediate use while extended function is also available through coding. In the simulation model, the OHT is constructed by movable objects called "Vehicles". A vehicle acceleration speed of ±0.2 m/s and a final speed of 1 m/s are given as object attributes. Several real world objects (e.g. diffusion tools, intrabay track and stockers) are also included in the simulation model as Fig. 86.7 shows.

Here, several major performance measures collected from the simulation model are outlined as follows.

(A) *Production performance*: There are four measures: (1) throughput (lots); (2) lot cycle time (seconds); (3) system WIP (lots); and (4) WIP in the stocker (lots).

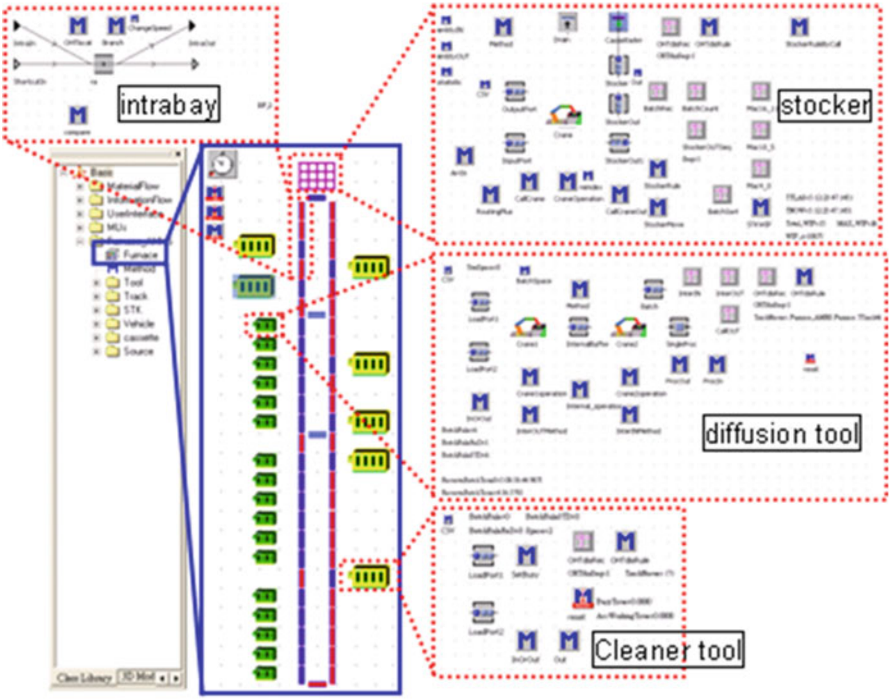


Fig. 86.7 The simulation model of a diffusion bay

(B) *Transportation performance*: Three major categories are included. (1) Delivery time: The time a vehicle is called by a source stocker or from the tool to the time the lot is placed on the load port or shelf of the destination tool or stocker. The time includes transport time and waiting time. (2) 95% Delivery time: The 95% lots can complete the movement at a certain time. (3) Transport time: The amount of time during the placement of the lot of the source tool's output load on a vehicle to the destination tool's input load port.

(C) *Vehicle movement performance*: There are two measures in this category. (1) Transport jobs: The quantity of lots that completes transport in this system during the simulation time. (2) Empty vehicle utilization: The percentage of available working time of an idle vehicle.

The experimental design for this study considers the operational factors such as the arrival rates of the input wafers, the number of vehicles, the form-batch size and the PDVA vehicle quantity. The arrival rate for the input wafers per month can be 18,000 or 25,000. The number of vehicles can be two, four, or six. The form-batch size can be four or six. The PDVA vehicle quantity can be one (without using the PDVA method), two, and four. Here, the combination of the arrival rate, the number of vehicles, the form-batch size, and the PDVA vehicle quantity can be treated as an operational scenario. We verify our model with iterations from simple output checks to a complex walkthrough using an event-list trace through the *eM-Plant* software. We validate our model using a "correlated inspection method". This involved collecting historical data from the wafer fab and comparing the model and system outputs of selected variables after the warm-up period. Using this method, we validate the throughput, cycle time, and WIP levels. Each simulation in our experiment ran for 30 days after a warm-up period of 2 days. Each experiment is replicated 30 times. Thus, the total number of simulation experiments performed is 2(the arrival rates) $\times$ 3(the number of vehicles) $\times$ 2(form-batch size) $\times$ 3 (PDVA vehicle quantity) $\times$ 30(replications) which equals 1,080.

All experimental data are adopted after a statistical residual test and then analyzed with ANOVA. Based on the simulation results, we conclude that production performance is affected by the lot arrival rate, form-batch size, and an interaction of these two factors. The indices of lot movement and vehicle movement performance are both significantly affected by the lot arrival rate, vehicle quantity, form-batch size, and PDVA vehicle quantity. There is further evidence showing that a 60% improvement in delivery time is observed when two to four vehicles are placed in the system, and an additional 30% improvement is reached when four to six vehicles are placed in the system. In addition, the system with a high (25,000 wafers/month) or low(18,000 wafers/month) arrival rate of input wafers could both achieve the best lot's delivery time when there are six vehicles to serve and the PDVA vehicle quantity is set to four instead of one or two. Consequently, the simulation result in transportation and vehicle movement performance shows that the PDVA method can improve vehicle arrival time and reduce lot waiting time for a diffusion bay.

Conclusion

This paper examines the vehicle assignment control problems for an AMHS system in semiconductor manufacturing. A pre-dispatching vehicle assignment (PDVA) method is proposed to assign the vehicles at the same time for a furnace tool or stocker in the diffusion area. The objective is to simultaneously assign idle vehicles for a furnace tool, which has a form-batch manufacturing step that will minimize the long vehicle waiting time of all transport jobs. The discrete-event simulation of an AMHS for a diffusion bay in a 300 mm wafer fab is analyzed, considering the effects of the vehicle assignment method. From the simulation results, we find that the PDVA method revealed substantial improvements in the AMHS transport performance. These simulation results lead to the conclusion that the PDVA method influences lot and vehicle movement performances. This inference is useful for fab managers to further study the PDVA method in other areas and continuously improve transport performance in the entire AMHS system.

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