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An Improved Dispatching Method (a-HPDB) for Automated Material Handling System with Active Rolling Belt for 450 mm Wafer Fabrication

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Abstract: The semiconductor industry is facing the transition from 300 mm to 450 mm wafer fabrication. Due to the increased size and weight, 450 mm wafers will pose unprecedented challenges on semiconductor wafer fabrication. To better handle and transport 450 mm wafers, an advanced Automated Material Handling System (AMHS) is definitely required. Though conveyor-based AMHS is expected to be suitable for 450 mm wafer fabrication, still it faces two main problems, traffic-jam problem and lot-prioritization. To address the two problems, in this research we have proposed an improved dispatching method, termed Heuristic Preemptive Dispatching Method using Activated Roller Belt (a-HPDB). We have developed some effective rules for the a-HPDB based on Activated Roller Belt (ARB). In addition, we have conducted experiments to investigate its effectiveness. Compared with the HPDB and R-HPD, two dispatching rules proposed in previous studies, our experimental results showed the a-HPDB had a better performance in terms of average lot delivery time (ALDT). For hot lots and normal lots, the a-HPDB had advantages of 4.14% and 8.92% over the HPDB and advantages of 4.89% and 8.52% over R-HPD, respectively.

Keywords: conveyor-based AMHS; 450 mm wafer fabrication; dispatching method

1. Introduction

The semiconductor industry has experienced outstanding advancements over the past five decades. There are two main factors driving these advancements. One is technology advancement and another is wafer size increment [1]. The technology advancements focused on minimizing the integrated circuit (IC) so as to pack more transistors into one IC chip to enhance its functionality. Following the Moore's rule, each of the wafer size transitions has nearly doubled the number of transistors in an IC chip [2].

The wafer size increments have led to the increase of IC dies. For example, for the last transition of wafer size from 200 mm diameter to 300 mm diameter, the IC dies resulting from one wafer has been increased as much as 2.25 times [1], which has enhanced the productivity considerably. Currently, the IC industry is transitioning from the 300 mm wafer to 450 mm wafer. A similar transitional benefit is expected.

However, due to their increased size and weight, 450 mm wafers will introduce unprecedented challenges on a wafer fab in terms of wafer handling, transport, factory configuration and process automation [3]. A capable Automated Material Handling System (AMHS) suitable for 450 mm wafer production is definitely required [4,5], and the AMHS plays an important role that can determine the success of wafer transition [6]. In the past, various kinds of AMHSs have been proposed to support wafer production. They include automatic guided vehicle (AGV), rail-guided vehicles (RGV), overhead shuttle system (OHS), overhead hoist transport (OHT) and conveyor [7]. Among these AMHS, OHT is the main system widely used in 300 mm wafer fabs. This kind of AMHS employs overhead transporters (such as vehicles) to directly access a stocker or a machine in a production line, with the efficiency of the OHT depending heavily on its control mechanism and the characteristics of its vehicles. The number of vehicles in the OHT is also critical as it can affect the performance of an OHT considerably; insufficient vehicles in an OHT can lead to long waiting times for lots while excessive vehicles will cause the traffic-jam problem [8]. The traffic jam problem can affect the performance of an AMHS considerably [9].

Compared to a vehicle-based AMHS, a conveyor-based AMHS can send a lot earlier due to the continuous flow of conveyor, which leads to the benefits of reduced waiting time and eventually shortened delivery time for lots. Another benefit found for a conveyor-based AMHS is that it can serve as a buffer for lots prior to their entering into a processing equipment. This can lead to the benefit of reduced number of stockers in an AMHS. One more benefit found for a conveyor-based AMHS is that it can maintain a higher entering rate of lots into a processing equipment [6,10]. Due to these advantages, researchers have suggested using conveyor-based AMHSs for 450 mm wafer fabrication [9,10].

In a wafer fab, a conveyor-based AMHS usually consists of two main parts: an Inter-bay loop and some Intra-bay loops. The Inter-bay loop is usually situated at the center of a factory and connects to several Intra-bay loops. The Intra-bay loops are used to transport lots within an Intra-bay while the Inter-bay loop transports lots between Intra-bays. In a conveyor-based AMHS, conveyors are the main device used to carry and transport wafers and these conveyors are moving along one direction. In an AMHS, it also includes sensors to detect lots so as to control the movements of these wafer lots. For instance, a get-out sensor is usually used at the end of the conveyor to detect wafer lots. In an Intra-bay, some similar machines are grouped with each machine equipped with a load/unload port for loading/unlading lots, one at a time. The load/unload port for 450 mm wafer production has been already standardized [11].

However, a traditional conveyor-based AMHS tends to encounter the traffic-jam problem due to the single direction movement of conveyors. Especially, when loading/unloading a lot into/from a machine it is likely to block the following lots, which makes the traffic-jam problem likely to happen. The blocking situation is especially likely to happen for an Intra-bay with higher loading of lots. In this research, we define *block time* as a delay time caused by block situation. The blocking situations can affect the delivery time of a lot considerably. To reduce block time, an effective dispatching method is definitely required. Besides the traffic-jam problem, the lot prioritization is another problem faced by an AMHS as some lots (called hot lots) require fast service to meet customer needs. While serving the hot lots, it also needs to minimize impacts on normal lots.

In this research, we have focused on addressing the two problems encountered in a traditional conveyor-based AMHS by proposing an improved methodology, termed Heuristic Preemptive Dispatching Method using Activated Roller Belting (a-HPDB). The a-HPDB is based on an advanced conveyor equipped with Activated Roller Belt (ARB) controlled by a programming script. To improve the efficiency of an AMHS with ARB, effective rules can be developed for the programming script to best control the movements of lots on an ARB. With some additional dispatching rules, the a-HPDB improves the HPDB proposed in [12]. It is expected to better dispatch and control the lots on an ARB-based AMHS with the priority of lot being also taking into account. To evaluate its effectiveness, we have conducted simulation experiments and compared a-HPDB with HPDB [12] and R-HPD [13]. Our experimental results showed a-HPDB outperformed HPDB and R-HPD in terms of average lot delivery time (ALDT).

The rest part of this paper is organized as follows. Section 2 includes a literature review indicating the main stream of the published theories in terms of semiconductor manufacturing, AMHS and the dispatching rules. Section 3 clarifies the main methodology used in this research. Section 4 presents simulation experiments, the experimental results and the analysis of the results. Section 5 gives some conclusions and offers future research directions.

2. Literature Review

In this section, we review some studies that have developed dispatching rules for wafer fabrication in terms of 300 mm and 450 mm wafer sizes.

For 300 mm wafer fabrication, Liao and Fu [14] proposed a dispatching rule, termed Modified Nearest Job First (MNJF), for an OHT with single loop. The dispatching rule aims to improve the throughput of lots while minimizing the delivery times. They found the dispatching rule was effective. Liao et al. [15] adopt Petri nets to model the coupling dynamics among transport jobs and OHT vehicles in an intrabay loop of a 300 mm wafer fab. In addition, they proposed a heuristic algorithm to adjust the dual solution to a feasible schedule. Numerical results demonstrated that their solution methodology could generate good schedules within a reasonable amount of computation time for realistic problems. Compared to a popular vehicle dispatching rule, their approach can achieve 25.6% improvements on the average delivery time in our realistic test cases. Li et al. [16] proposed an adaptive dispatching rule (ADR), whose parameters are determined dynamically by real-time information relevant to scheduling, for semiconductor fabs. A real fab simulation model was used to investigate the effectiveness of the ARD. Their simulation results showed that ADR with constant weighting parameters outperforms the conventional dispatching rule on average. Lin et al. [17] proposed a hybrid push/pull (PP) dispatching rule for an AMHS. In addition, they had conducted simulation experiments to investigate the effectiveness of the dispatching rule. Their simulation results showed that the PP could reduce WIPs as well as delivery time of lots significantly. Liao and Wang [18] proposed a differentiated preemptive dispatching policy (DPD) to prioritize lots in a 300 mm fab, with hot lots being served first. Finally, they suggested that an OHT transporter should keep distance from the front OHT transporter to prevent blocking situations. In another study, Wang [19] proposed a Heuristic Preemptive Dispatching Method (HPD) to reduce the waiting times and eventually the delivery times of lots in an OHT of a 300 m wafer fab. Their simulation results showed that the HPD was effective. However, as these aforementioned dispatching rules were dedicated to the OHTs used in a 300 mm wafer fab, they may not be suitable for the conveyor-based AMHS to be used for 450 mm wafer fabrication. Thus, effective dispatching methods suitable for the conveyor-based AMHSs to be used in a 450 mm fabrication environment are still required.

There are some studies dedicated to developing dispatching rules for 450 mm wafer fabrication and they are reviewed as follows. Duong [20] proposed a Heuristic Preemptive Dispatching Method (HPD) for a conveyor-based AMHS in a simulated 450 mm wafer fab. Their experiments showed that the HPD was effective due to promising delivery times for both hot and normal lots. Further, Wang et al. [12] proposed a novel dispatching method, termed Heuristic Preemptive Dispatching Method using Activated Roller Belt (HPDB), a novel method with effective dispatching rules based on a kind of advanced belt, the ARB. The HPDB nearly improved the problems found in the HPD [18] and R-HPD [13]. However, while the HPDB only allows a lot to directly transfer from Intra-Line 1 to Intra-Line 2 so as to access the empty machines on Intra-Line 2, it cannot best utilize the empty machines on Intra-Line 1. This has prompted us to improve the HPDB by proposing a new dispatching method, termed a-HPDB. The a-HPDB allows a lot to change between Intra-Line 1 and Intra-Line 2 freely so as to access available machines on both sides. We detail the a-HPDB in the next section.

3. Methodology

3.1. Restructuring a Traditional AMHS Using ARB

3.1.1. Introduction to the ARB

Figure 1 shows the configuration of an ARB. One essential part of the ARB is polyurethane rollers whose core are made of acetal. The diameter of these rollers is 22.3 mm and rollers are skewed either 45° from travel direction of belt. When these belt rollers are activated, products will move faster than the belt's speed; otherwise, the product travels at the belt's speed. The product behavior will vary according to its shape, weight, conveyor design, and belt speed. Custom belts consisting of any combination of 0°, 30°, 45°, or 60° are available. Custom belts can also include rollers oriented in different directions.

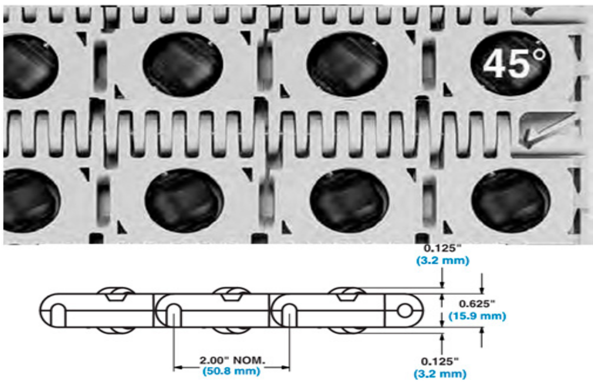

Figure 1. Intralox conveyor Belting Series with 45° Angled Roller.

Figure 2 shows the example of an AMHS with ARB conveyor. On the ARB conveyor, products are resting on the free-turning angled rollers instead of on the belt surface. These rollers stretch above and below the belt surface and are situated at an angle that correlates with the moving direction of belt travel. Rollers that are activated by the carry way surface beneath move products across the belt in the moving direction of roller orientation instead of the moving direction of belt travel. The ARB can move items specifically and selectively, and it can alter the direction, arrangement, location, and speed of a product independently.

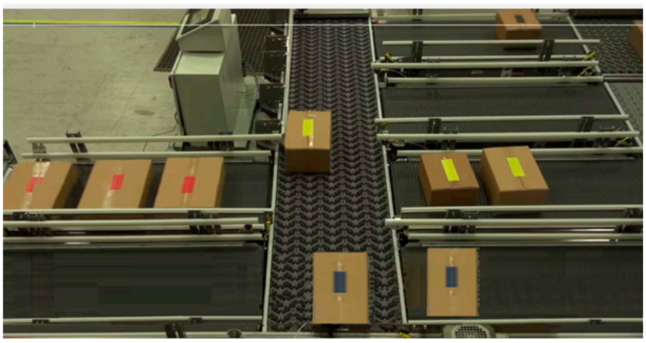

Figure 2. The example of an AMHS (Automated Material Handling System) with ARB (Activated Roller Belt) conveyor.

3.1.2. Restructuring an AMHS

- *Remove the curved-conveyor in the Inter-bay*. Same as [12], the 1st structural change is removing the curved conveyor in the Inter-bay so that the two main lines of Inter-bay can be coupled to allow lots to change line between the two main lines freely.
- *Replace traditional conveyor with ARB*. Same as [12], the 2nd structural change is replacing all traditional conveyors with ARB as an ARB provides higher capability for lot movements.
- *Add one short line of ARB (L&UL line) in front of each machine.* Same as [12], Figure 3 shows the 3rd structural change in which two short ARB conveyors, called "Load & Unload line" (L&UL line), are added in front of each machine. The first ARB conveyor (called Load Port) allows an incoming lot to access the machine and the 2nd ARB (called Unload Port) allows a processed lot to leave the machine. A robot is used for loading and unloading. The L&UL line helps avoid blocking the following lots in Intra-Line when loading/unloading a lot.
- *Couple the Intra-Lines 1 and 2 in an Intra-bay.* Same as [12], Figure 4 shows the 4th structural change in which the connecting conveyor in an Intra-bay is removed and the Intra-Line 1 and Intra-Line 2 are coupled. This change allows a lot to change line between two Intra-Lines freely, which can shorten the travel distance.

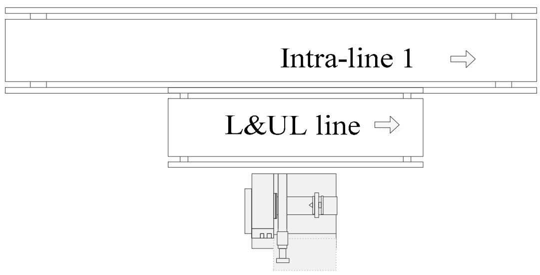

Figure 3. Add one short ARB segment (L&UL line) in front of each machine.

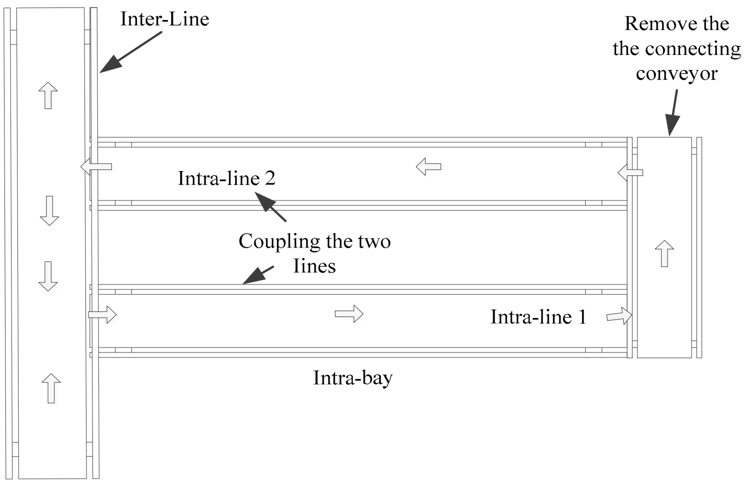

Figure 4. Couple Intra-Line 1 and Intra-Line 2 in an Intra-bay.

3.2. The a-HPDB Method

The efficiency of an ARB conveyor mainly depends on a programmed script. To achieve a good efficiency, we can develop effective dispatching rules for the script to control the ARB conveyor.

3.2.1. The Dispatching Rules

- *The unprocessed hot lot (uH) first (Rule 1).* As shown in Figure 5, if there is an uH following an unprocessed normal lot (uN) in a row moving toward the nearest machine within the distance D1 then the uH has the priority to reserve that machine. As a result, other uN keep moving in the Intra-bay.
- *First come first serve for uNs (Rule 2).* Figure 6 shows that if there are uNs within the distance D1 moving toward the nearest empty machine then the first uN has the priority to reserve that machine. As a result, the other uNs will keep in the Intra-Line. As the loading and unloading happening in the L&UL of a machine, it will not block other lots in the Intra-Line.
- *Directly move a processed lot (pL) to Intra-Line 2 (Rule 3).* As shown in Figure 7, unload a pL (either processed hot lot (pH) or processed normal lot (pN)) first from a machine to the L&UL line. Then, based on the position of the processing machine, either move the pL directly to Intra-Line 2 if the machine is on Intra-Line 2 side (as shown in Figure 7a) or first move the pL to Intra-Line 1 and then to Intra-Line 2 if the machine in on Intra-Line 1 side (as shown in Figure 7b). This rule expedites the exit of a pL from an Intra-bay.
- *Directly move an uH from Intra-Line 1 to Intra-Line 2 (Rule 4).* As shown in Figure 8, when there is an uH moving in the Intra-Line 1, meanwhile an empty machine in the "Quick area" (a set of machines locates within the distance between the current position of the uH and the exit of this Intra-bay) is available, immediately transfer the uH to Intra-Line 2 to directly access that empty machine.
- *Directly move an uL to Intra-Line 1 from Intra-Line 2 (Rule 5).* As shown in Figure 9, when an uL (an unprocessed hot lot or normal lot) is moving in Intra-Line 2 there is meanwhile an empty machine in Intra-Line 1, then the AMHS controller directly moves the uL to Intra-Line 1 to access that empty machine.
- *Reserve the nearest machine to the Intra-bay for hot lots (Rule 6).* Figure 10 shows the 6th dispatching rule in which the nearest machine to Inter-Line is reserved for hot lot. This can enhance the chance for the nearest machine to serve hot lots. As a result, the hot lots can enjoy a higher service priority and leave an Intra-bay more quickly. When an Intra-bay has far less hot lots than normal lots, it ensures hot lots to be mostly served by this reserved machine to result in a desired system performance.
- *Skip occupied machine (Rule 7).* As shown in Figure 11, this rule aims to shorten the travel distance for a hot lot. If some specific machines are not available then an unprocessed lot (uL) such as the L1 can skip these machines and directly change from Intra-Line 1 to Intra-Line 2 to skip unnecessary traveling.

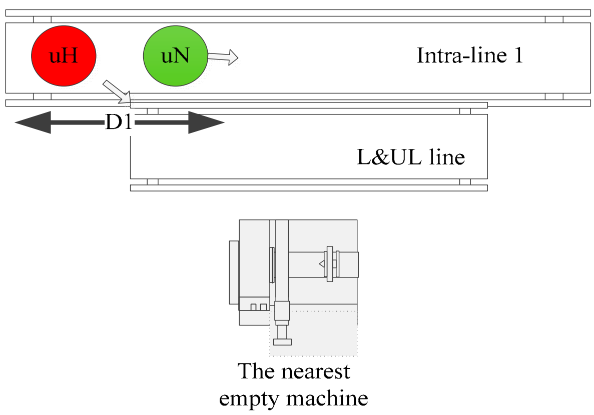

Figure 5. The unprocessed hot lot (uH) first (Rule 1).

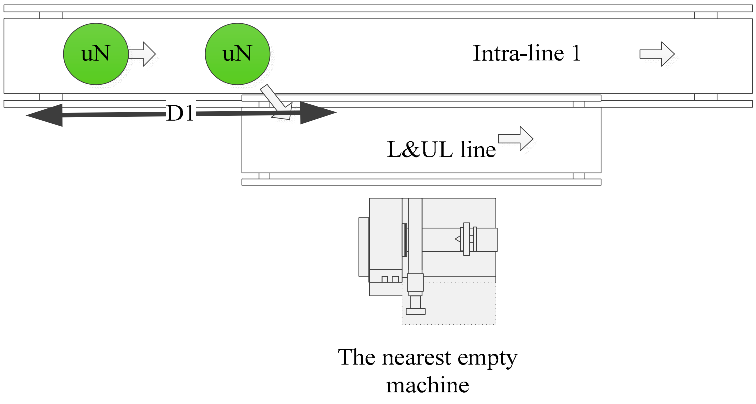

Figure 6. First come first serve for uNs (Rule 2).

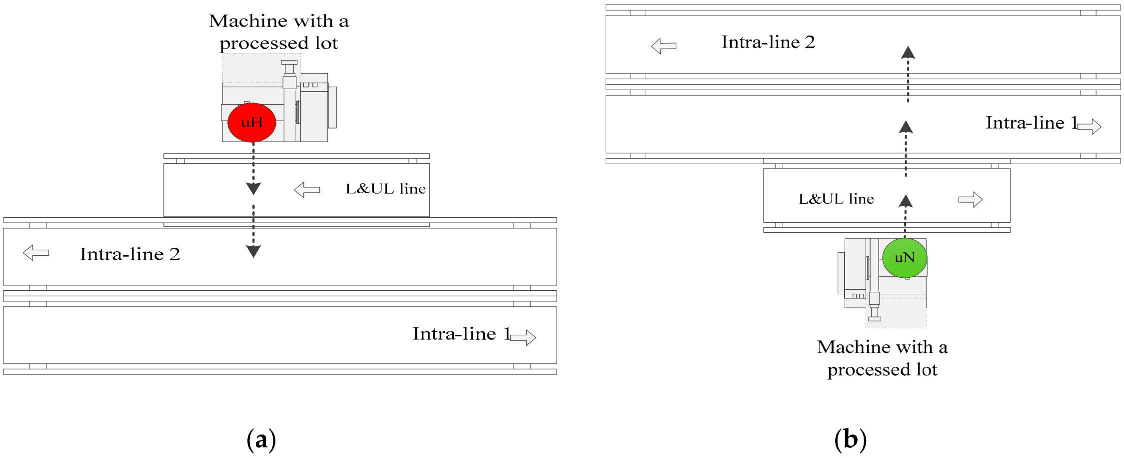

Figure 7. (**a**) Directly move a pL to Intra-Line 2 (**b**) first move a pL to Intra-Line 1 and then to Intra-Line 2 (Rule 3).

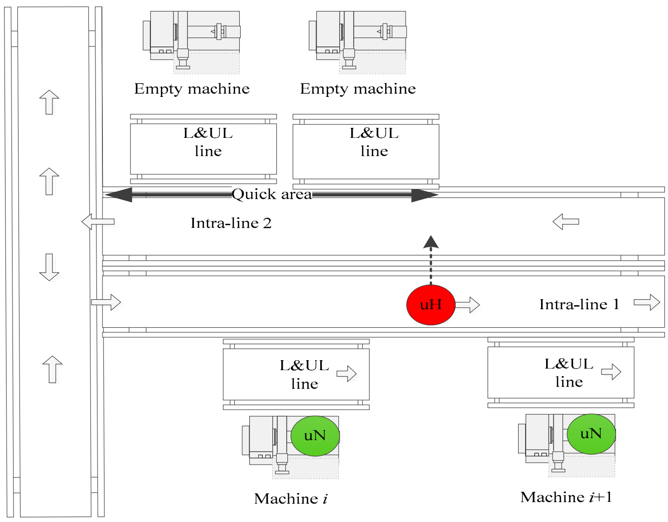

Figure 8. Directly move an uH to Intra-Line 1 from Intra-Line 2 (Rule 4).

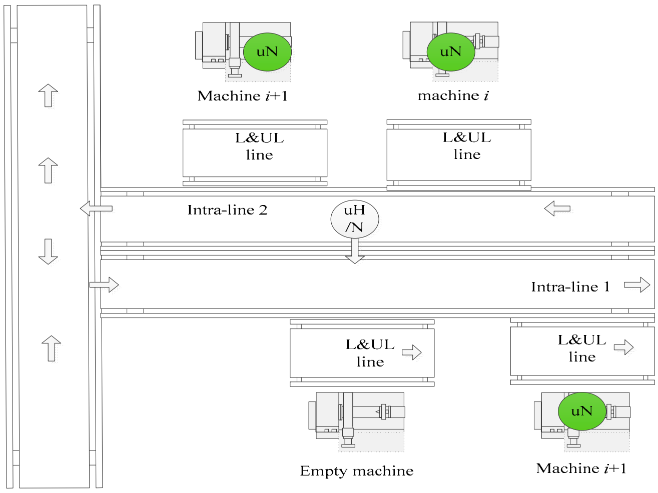

Figure 9. Directly move an uL to Intra-Line 1 from Intra-Line 2 (Rule 5).

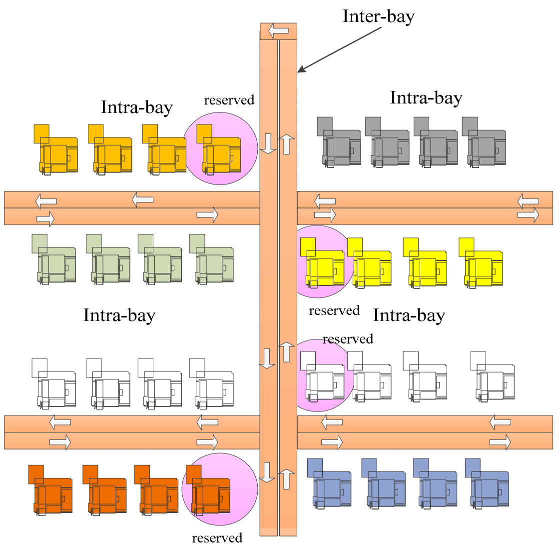

Figure 10. Reserve the nearest machine to the Intra-bay for hot lots.

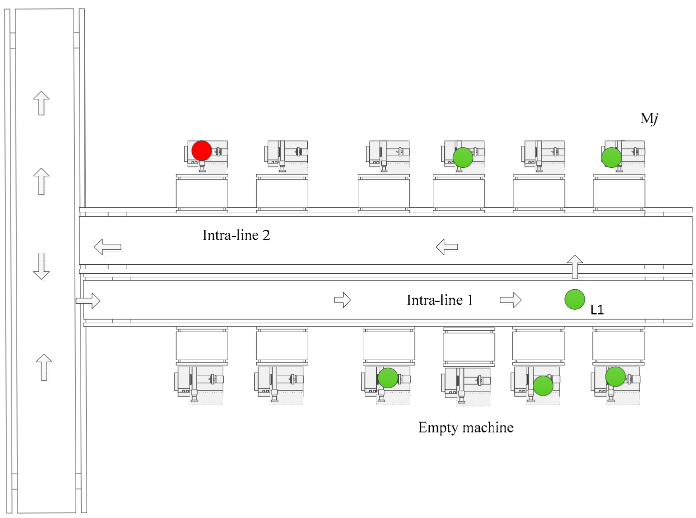

Figure 11. Skip occupied machine.

3.2.2. Flow Chart

Figure 12 shows the flow chart of the proposed a-HPDB method. In this research, C language was used to implement the a-HPDB. We detailed the flow chart as follows.

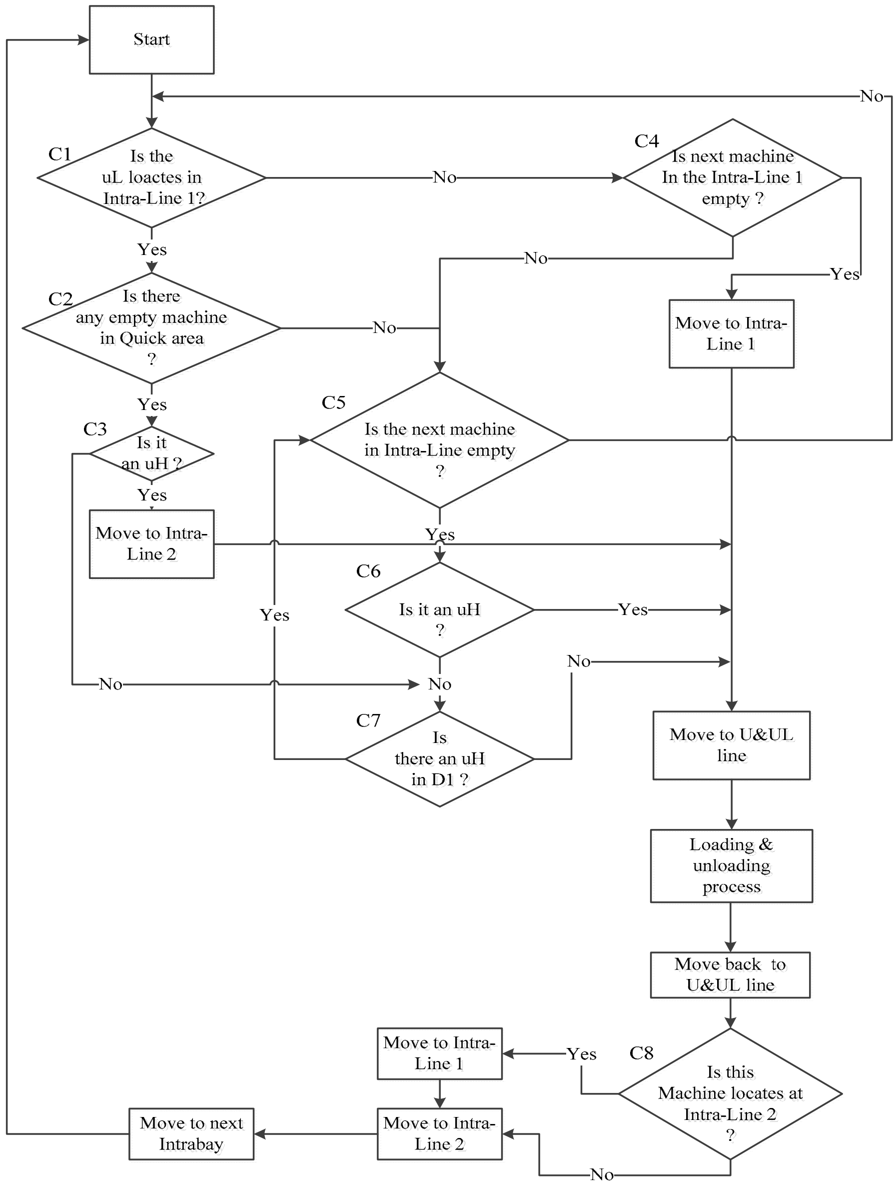

Figure 12. The flow chart of the a-HPDB (Heuristic Preemptive Dispatching Method using Activated Roller Belting) method.

For an incoming uL (uH or uN), the AMHS controller first checks whether the uL locates at the Intra-Line 1 (C1). If "yes" then the AMHS controller continues to check whether there is an empty machine in the "Quick area" (C2). If "yes" the AMHS continues to check whether the incoming uL is a hot lot (C3). If "yes" the AMHS controller then directs the uH to the Intra-Line 2 to access that empty machine immediately; Otherwise, it keeps the uN moving in the Intra-Line. At C1, once an uL is moving in the Intra-line 2 and the AMHS controller finds out there is an empty machine in the Intra-Line 1 (C4), then the controller immediately transfers that uL to the Intra-Line 1 to access that empty machine. At C4, if there is no empty machine in the Intra-Line 1 the AMHS controllers continues to check whether the next machine is available (C5). If "yes" the AMHS controller further checks whether the uL is a hot lot (C6). If "yes" then the controller directs the uH to access the next machine; Otherwise, while the incoming lot is an uN, the AMHS continues to check whether there is any uH within the distance D1 of the next machine (C7). If "yes" the controller continues the movement of the uN in the Intra-Line; Otherwise, the controller directs the uN to the next machine. Having processed by a machine, a pL is unloaded back to the U&UL line of the machine and C8 is used to check the position of the machine. For a machine on the Intra-Line 1, the controller transfers the pL to Intra-Line 2 to speed up the exit from this bay.

4. Simulation Experiments and Results

This section details the simulation experiments and analyzes the experimental results.

4.1. Simulation Experiments

4.1.1. The Simulation Model and Environment

FlexSim software (Flexsim-3D 7.7.2, FlexSim Software Products Inc., Orem City, UT, USA, 2016) was used in this research to build the simulation model. Figure 13 shows the simulation model that includes one Inter-bay and five Intra-bays for 450 mm wafer fabrication. The simulation environment is detailed as follows.

Figure 13. The simulation model.

- The total simulation horizon is set to 2 weeks (14 days), and the fab runs 24 h a day; and 7 days a week. The first 7 days is the "warm-up" time. The time unit used for simulation is second.
- This simulation model includes 1 Inter-bay and 5 Intra-bays. A total number of 69 sets of machines are distributed in five Intra-bays. The Inter-bay is 145 feet long and each Intra-bay is 100 feet long.
- Each wafer lot in the fab contains 12 pieces of 450 mm wafers.
- The inter-arrival time of transport is probabilistic and assumed to be of exponential distribution.
- The AMHS is equipped with ARB conveyors that move with one direction.
- Both hot lot and normal lot are considered in this system.
- The loading time and unloading time of a lot are assumed to be fixed (5 s).
- The normal speed of ARB is 1 ft/s and the normal travel speed of a lot from a line to another is assumed to be 0.5 ft/s.
- No failures and activities on the conveyor and device during the simulation process.
- Each machine can load/unload a lot at a time.

4.1.2. Performance Index

For a factory to achieve a better result, it needs to reduce the lot delivery time (*LDT*) as much as possible. Equation (1) defines the formula to calculate the *LDT* for a lot.

$$LDT = TT + L\&ULT + WT + BT \quad (1)$$

where

TT: is the total transportation time for a lot from entering the system to exiting the system.
L&ULT: is the total time of a lot being loaded and unloaded from machines.
WT: is the total waiting for a lot to be loaded into a machine for processing.
BT: is the total block time of a lot.

Theoretically, the *L&ULT* is fixed time and cannot be improved whereas the *TT*, *WT* and *BT* are variable times and can be improved by an effective dispatching method.

Equation (2) defines the average lot delivery time (*ALDT*), where *i* indicates the *i*th lot and *L* is the total number of lots, which is used as the main performance index in this research.

$$ALDT = \left(\sum_{i=1}^{L} LDT_i\right)/L \quad (2)$$

To investigate different scenarios, the bay-loading ratio ($R_{BL}(j)$) and hot lots ratio ($R_h(j)$) are combined to represent a system configuration for an Intra-bay. The higher the $R_{BL}(j)$ and $R_h(j)$ indicates a higher degree of traffic-jam in a bay. A system configuration is denoted as XHYB, where X is the hot lot ratio and Y indicates the bay-loading ratio.

Equation (3) is the formula for calculating $R_{BL}(j)$ for an Intra-bay *j*, which is the average number of hourly input lots divided by the maximum number of hourly output lots per bay.

$$R_{BL}(j) = \sum_{i=1}^{m} (3600s/\ ST_i + PT_i + \varphi_i) \quad (3)$$

where

m: is the total number of machines in Intra-bay *j*
i: the machine *i*, *i* = 1, . . . ,*m*
j: the bay *j*
ST_i: is the setup time of machine *i*
PT_i: is the processing time of machine *i*
φ_i: is the loading and unloading time of machine *i*

The bay-loading time of an Intra-bay is calculated for 1 h, and the time unit is second. In this research, three bay loading ratios 92%, 96% and 98% are used.

Equation (4) defines the formula for calculating the hot lot ratio, $R_h(j)$. The increase of $R_h(j)$ can affect the delivery of normal lots. In this research three hot lot ratios 2%, 6% and 10% are used.

$$R_h(j) = u_j/\rho_j \quad (4)$$

where

u_j: is the average number of hot lots
ρ_j: is the average number of lots in Intra-bay *j*

4.2. Simulation Results and Analysis

To investigate its effectiveness, we compared simulation results of a-HPDB to those obtained from (HPDB) [10] and R-HPD [11] under different system configurations.

4.2.1. Simulation Results

Table 1 shows the experimental results based on data from the 8th day to the 14th day. To facilitate comparison, Figures 14 and 15 depict the ALDTs of hot lots and normal lots obtained from HPDB, R-HPD and a-HPDB at different system configurations. The analysis and discussion are as follows.

Table 1. Comparisons of different methods.

System Configuration		*ALDT* (Second)					
		Hot Lot			Normal Lot		
Hot-Lot Ratio	Bay-Loading Ratio	RHPD	HPDB	a-HPDB	R-HPD	HPDB	a-HPDB
2	92	616.31	549.61	517.365	1509.53	1406.77	1294.165
	96	648.21	587.29	542.402	1876.66	1696.43	1557.271
	98	700.25	605.48	574.72	2347.04	2048.09	1857.495
6	92	620.12	550.86	543.689	1543.21	1439.35	1321.222
	96	655.13	586.93	566.773	1926.69	1762.41	1590.739
	98	696.92	614.25	587.97	2467.36	2125.88	1958.656
10	92	633.36	568	552.095	1594.88	1480.74	1351.393
	96	667.02	594.09	575.93	2045.46	1827.28	1660.943
	98	722.36	635.24	611.449	2699.24	2323.78	2082.479
Average		662.19	587.97	563.6	2001.12	1790.08	1630.48
Reduce (%)		**14.89%**	**4.14%**		**18.52%**	**8.92%**	

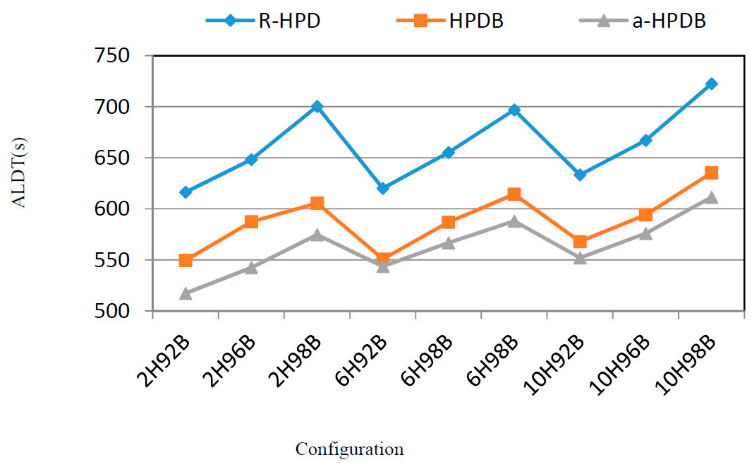

Figure 14. Simulation results of hot lots at different system configurations.

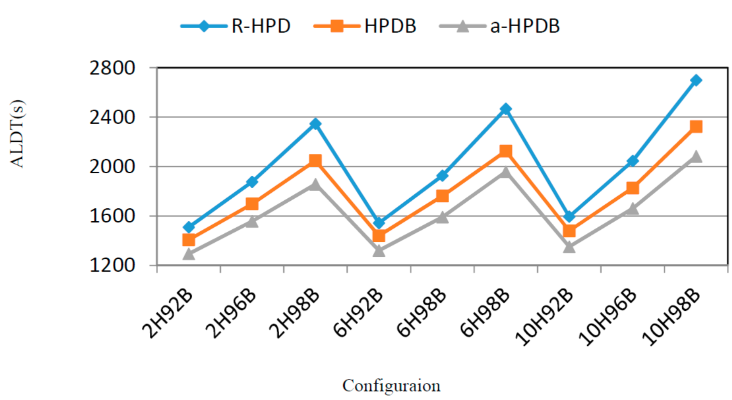

Figure 15. Simulation results of normal lots at different configurations.

4.2.2. Analysis and Discussion

1. Figures 14 and 15 show that a-HPDB outperforms HPDB and R-HPD in terms of ALDT for hot lots and normal lots, respectively.
2. Figure 14 shows that a-HPDB has the highest ALDT reduction for hot lots at the system configuration 2H96B (2% hot lot ratio and 96% bay loading). The advantages over HPDB and R-HPD are 7.64% and 16.32%, respectively. Figure 15 shows a-HPDB has the highest ALDT reduction for normal lots at the system configuration 10H98B. The advantages over HPDB and R-HPD are 10.38% and 22.85%, respectively.
3. Overall, for hot lots a-HPDB has a 4.14% and 14.89% fewer ALDTs than HPDB and R-HPD, respectively; for normal lots a-HPDB has an 8.92% and 18.52% fewer ALDTs than HPDB and R-HPD, respectively.
4. In addition, Figures 14 and 15 show that the higher the bay-loading ratio the higher the advantage for a-HPDB. For example, at the system configuration 10H92B, for hot lots the ALDTs obtained from a-HPDB, HPDB and R-HPD are 552.1 s, 568 s and 633.36 s, respectively, indicating that a-HPDB has a 2.8% edge over HPDB and a 12.83% edge over R-HPD. For normal lots, a-HPDB has an 8.74% edge over HPDB and a 15.27% edge over R-HPD. At the system configuration 10H96B, for hot lots a-HPDB has a 3.06% edge over HPDB and a 13.66% edge over R-HPD. For normal lots a-HPDB has a 9.1% edge over HPDB and an 18.8% edge over R-HPD. At the system configuration 10H98B, for hot lots a-HPDB has a 3.75% edge over HPDB and a 15.35% edge over R-HPD. For normal lots a-HPDB has a 10.38% edge over HPDB and a 22.85% edge over R-HPD.
5. Table 2 shows the AMHS efficiency obtained from a-HPDB, HPDB and R-HPD under different system configurations. It is found that the higher the bay loading the higher the efficiency for a-HPDB. This characteristic is especially important for a firm that faces increasing demands.
6. Note that the HPDB improved the R-HPD. In this research, the a-HPDB further improved the HPDB. The improvement mainly comes from the three additional dispatching rules (Rules 5, 6 and 7) used in the a-HPDB. Especially, rule 5 enables a wafer lot to direct change from Intra-Line 2 to Intra-Line 1. As a result, together with Rule 4, the a-HPDB allows a lot to change between two Intra-Lines to access an available machine. In contrast, the HPDB only allows a lot in Intra-Line 1 to access the available machines in Intra-Line 2. Nevertheless, we believe Rules 5, 6 and 7 all have contributions to the advantage of the a-HPDB method.
7. From the experimental results, we concluded that a-HPDB is the best one among the three methods as it can best deal with the "traffic-jam" problem while considering lot priority.

Table 2. The efficiency of a-HPDB under different bay-loading ratio.

System Configuration	Hot Lot		Normal Lot	
	$\frac{a-HPDB}{R-HPD}$	$\frac{a-HPDB}{HPDB}$	$\frac{a-HPDB}{R-HPD}$	$\frac{a-HPDB}{HPDB}$
10H92B	12.83%	2.8%	15.27%	8.74%
10H96B	13.66%	3.06%	18.8%	9.1%
10H98B	15.35%	3.75%	22.85%	10.38%

5. Conclusions

Leading semiconductor companies are undertaking their best efforts in the transition from 300 mm to 450 mm wafer fabrication, and they have achieved initial success. The development of an effective dispatching method for an AMHS to support wafer fabrication is also critical. Though some researchers have found that conveyor-based AMHS were suitable for 450 mm wafer transport, this kind of AMHSs remains to face the traffic-jam problem and the lot prioritization problem.

To address the two problems, we have proposed a novel dispatching method, termed as a-HPDB, based on an AMHS restructured by ARB conveyor. Our simulation results showed that the a-HPDB outperformed two other methods, HPDB and R-HPD, proposed in previous studies. In terms of ALDT, for hot lots, a-HPDB is 4.14% better than HPDB and is 14.89% better than R-HPD; for normal lots, a-HPDB is 8.92% better than HPDB and 18.52% better than R-HPD. In addition, it is noted that the ALDT of normal lots is not much affected in case of higher bay-loading and hot-lot ratios. This characteristic is especially important for a fab facing increasing demand.

Though we have demonstrated the advantages of restructuring AMHS using ARB, the use of ARB for the AHMS to be used in a 450 mm wafer fab should be prudent as both ARB and 450 mm wafer are new initiatives. More investigations and experiments are still required. For example, due to the increased weight and size, the 450 mm wafers will become more sensitive to vibration, thus more investigations are required to ensure the safety of wafers when transporting and handling these wafers. In addition, a thorough evaluation on the investment of ARB-based AMHS is also required. In future research, the development of more effective dispatching rules for the a-HPDB can be focused. In addition, the use of more intelligent optimization methods, such as the hybrid estimation of distribution algorithm [21], the genetic algorithm (GA) [22] and the particle swarm optimization (PSO) [23,24], can be considered in future study. Furthermore, enlarging the simulation model to full-scale AMHS is another research direction.

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