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The Improvement of Lot Delivery Time in 450 mm Semiconductor Manufacturing

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Abstract: Semiconductor industry has tremendous development in recent decades. According to Moore's Law [1], semiconductor wafer manufacturers have to search improvement opportunities constantly in order to be competitive. International technology roadmap for semiconductor [2] has indicated the possible scenarios for 450 mm wafer fabs, and the conveyor will be a potential solution to realize transportation automation. How to reduce the bottleneck of transportation is a valuable issue for the highly capital intensive industry. The purpose of this paper is to focus on improving the bottleneck of conveyor loops and provide effective transport dispatching rule for 450 mm wafer fab. The results demonstrate that controlling the speed of bottleneck loops can expedite the movement of lots and reduce lot transport time with the range from 6.24% to 13.02% without more input resources. These results are also verified by statistics. So the proposed rule can effectively reduce product cycle time in 450 mm wafer fab under conveyor transportation environment.

Keywords: AMHS, conveyor, 450 mm, semiconductor manufacturing, speed

1 Introduction

Semiconductor industry develops rapidly in recent decades, and it has become a crucial economic indicator all over the world. According to Moore's Law [1], semiconductor wafer manufacturers have to search opportunities constantly in order to improve productivity while reducing costs and cycle times within wafer fabs. Following the increase of wafer size, the cost of wafer manufacturing will be reduced by economy of scale. With the improvement and growth in technology, international technology roadmap for semiconductor [2] forecasts the trend of wafer manufacturing, wafer size evolution, future trends in the 450 mm wafer fab and the concept of next generation factory (NGF). Figure 1 points out a typical wafer generation pilot line, and it applies forecast timing targets of the 450 mm wafer generation, which expects the 450 mm wafer fab will start development from 2012.

Intel provides an economic perspective, that the development of the wafer size of can reduce manufacturing costs in 450 mm wafer fab [3] . The weight of 450 mm wafer fab is too heavy to transport manually, therefore the automated material handling system (AMHS) is more important for lots transportation and cycle time control in fabs. There are several

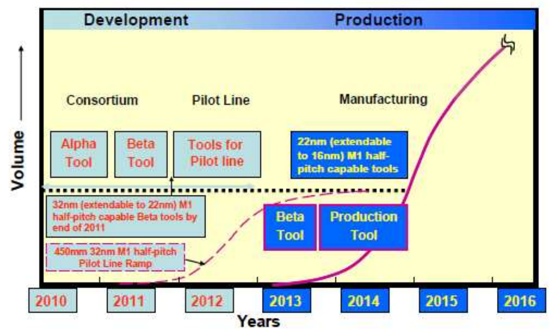

Fig. 1 The 450mm pilot line and production ramp curve [2]

transports of AMHS in wafer fab, including automatic guided vehicle (AGV), rail-guided vehicles (RGV), overhead shuttle (OHS), and overhead hoist transport (OHT), conveyor, and so on. The 300 mm AMHS usually uses the OHT to transport the lot [4] . But in the 450 mm semiconductor fab, the weight of wafer and process time increased, some scholars confer on conveyor transport as the main transport tool. Nazzal and Johnson [5] describe

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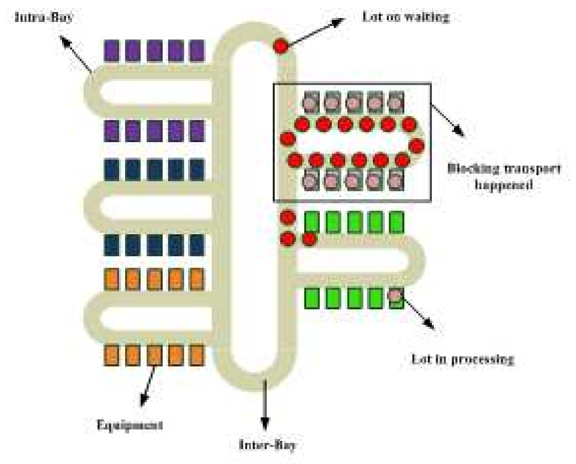

Fig. 2 Blocking transport happened

continuous flow transport (CFT) such as conveyors, provide higher transport capacity, shorter and more predictable delivery times, and lower cost than other traditional AMHS methods.

The transportation areas have two major portions: one is interbay loop of transfer among production centers; another one is intrabay loop of transfer within a production center. The interbay material handling systems is set in the center and connected all bays at bay's warehouse. An intrabay loop includes the sensor to detect the finished products, conveyor rail and equipment's load ports. The lot moves along the conveyor rails, and continuously moving in the same direction. When the lot reaches equipment, the equipment catches the lot automatically. However, when the bottleneck happened, normally the equipment is broken unexpectedly or over planning orders or production line unbalance, then the transport on downstream is blocked, and the goods on front conveyor will also be blocked (shows in Figure 2). The block is a big impact of cycle time. AMHS should provide the transport services to minimize lots delivery delays.

The purpose of this study explores the issues of performance enhancement for AMHS in the 450 mm wafer fab. In 450 mm wafer environment, the conveyor has a better position to replace the OHT cars, rails and stockers, and then it will become fully automatic. The AMHS should provide the transport services to minimize the delay of transport with least impacts to the delivery in 450 mm.

In semiconductor manufacturing, AMHS plays a significant role for lots transportation and cycle time control. Many scholars proposed related literature discussion. Liang and Wang [6] mention that AMHS has five major components, interbay, intrabay, OHT, track, and stocker. Kong [7] introduces the AMHS simulation steps by following the production steps. Wu et al. [8] develop manufacturing executed system (MES) and material control system (MCS) software to collect data of tools and material handling system in real time, which makes the dispatching of AMHS more feasible. Some scholars pay attention to prioritized lots handling issues. Liao and Wang [9] use neural network combined with heuristic method to handle prioritized lots and delivery time forecasting in 300mm intrabay. Moreover, an effective OHT dispatching rule; differentiated preemptive dispatching (DPD) policy is developed to reduce the possible blocking effects during the transportation of hot lots in a 300 intrabay system [10]. Wang [11] propose a differentiated lots dispatching for the whole factory scale. The simulation technique is used to verify the application of environment for one interbay and several intrabays. Another effective dispatching rule, named heuristic preemptive dispatching (HPD) rule is developed to resolve this heavy traffic jam of AMHS environment. This HPD uses a simulation method for a 300 mm wafer manufacturing factory to analyze the issue and verify the results [12] .

According to the document of International SEMATECH [4], among the proposed solutions to 300 mm AMHS implementation, overhead hoist transport (OHT) is one of the most promising technologies in realizing transportation automation in an intrabay, especially goods for the operation environment where both automatic and manual carrier transfer operations have to exist simultaneously. In 450 mm AMHS forecast, the wafer weight and size make the manual carrier transfer not realistic on semiconductor fab, only complete automatic carrier transfer could work well. Therefore, some studies have described the advantages of using conveyors, referred to continuous flow transporters (CFT), as the primary AMHS technology within the 450mm manufacturing [2,3,5]. Figure 3 depicts a 450 mm factory using 100% conveyor as transportation. Schmidt and Jackman [13] mentioned re-circulating conveyors provide both a delivery mechanism and a buffer for queuing behavior. Although these systems are commonly found in flexible manufacturing systems and assembly systems, accurate analytical models for performance evaluation have not been available. Coffman and Ngelenbe [14] analyze conveyor queues in a flexible manufacturing system, they study the effect of the distance separating the input and output points of a workstation, where one or two robots unload and load parts from and to the conveyor. Nazzal and Johnson [5] proposed an analytical model useful in the design of conveyor-based AMHS, the objective is to correctly estimate the work-in-process on the conveyor and assess the system stability. A numerical example is provided to demonstrate and validate the queuing model over a wide

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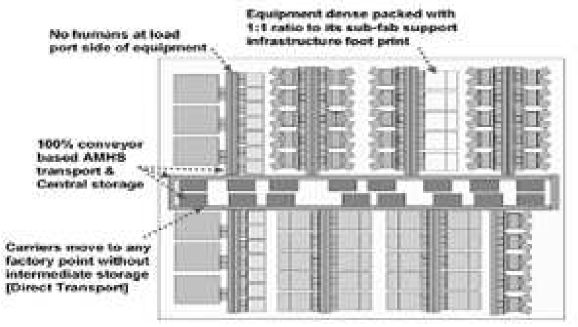

Fig. 3 factory, facilities and AMHS vision

range of operating scenarios. The results indicated that the analytical model estimates the expected work-in-process on the conveyor with reasonable accuracy. The CFT's provide higher transport capacity, shorter and more predictable delivery time, and lower cost-of-ownership than other traditional AMHS methods. Conveyors also provide local buffering of material at the processing tool level. The CFT solution for local buffering reduces the need for large stockers or larger process tool footprints. Cancelling the stocker or process tool footprints makes cost down and reduces the need of fab space.

However, bottleneck could be one of the most important impacts for lots delivery. Fowler et al.[15] remarks that "The presence of bottlenecks implies that careful attention and control in areas not directly influencing the bottleneck may have little effect on system performance". Koo et al. [16] describes that a system's throughput is usually determined by bottleneck resources, which is the fundamental principle of the theory of constraints (TOC). The marginal value of time at a bottleneck resource is equal to the throughput rate of the whole production system while the marginal value of time at a non-bottleneck resource is negligible. Therefore, the system performance can be improved by focusing on the bottleneck resource.

No researchers study the impact of bottleneck with conveyor system for 450mm fab. Therefore, the purpose of this paper is to focus the bottleneck of conveyor loops and provide effective transport speed control system for conveyor which will change the speed of bottleneck loops under 450 mm wafer fab. The objective of this method is to minimize the transport delay of lots and to convey our idea for lots transport services. A simulation model is an imitation which is based on SEMATECH 450 mm Guidelines [17].

This research is organized as follows. Sectio 2 presents our research methodology and explains how to compare the methods from simulation systems. Experiment design to verify is described in section 3. Section 4 provides analytics results and statistical test. Eventually, section 5 states conclusion and offers the future research directions.

2 Research Methodology

This chapter reveals the issue of 450 mm transportation rule of lots and bottleneck machines. This study provides effectively transport dispatching rule for lots which proposes the speed temper method of bottleneck loops to reduce product cycle time.

In 300 mm wafer fab, when the speed of vehicle increases, the lot delivery time will be saved. Hence, this research provides the way of speed control to improve the performance in 450 mm wafer fab. This study defines a transport job as a macro of transfer commands, including (1) when lot processing is conducted in a processing machine, the machine will transmit a delivery signal, (2) the machine sends the lot to the conveyor by load/unload for delivery, (3) the interbay turnout-sensor determines whether the lot has been completely processed, (4) if the lot was completely processed, it will be released to the interbay. Otherwise it will remain re-entrant in the intrabay, while waiting for the completion of processing and release. Conveyor delivery time is defined as the time to complete a transport job. This study will choose nearest job first (NJF) rule for the comparison. The NJF rule utilizes the straightforward idea of first meets, first serves. It has been suggested as a good dispatching rule in many OHT and conveyor applications [18]. And then, compare the results of NJF and the proposed rule of this study.

The heuristic algorithm overall rule is designed in details as below and shows in Figure 4.

Step 1: Temper detects the bottleneck loop and controls the speed ratio.

Step 2: The lot moves into interbay by conveyor, and waits to enter intrabay.

Step 3: The lot moves into intrabay by conveyor.

Step 4: MCS will detect if there is any available equipment; if yes, the lot will be pushed into equipment and processing; otherwise, it will rotate and wait on conveyor again. This transportation follows NJF rule. The conveyor will carry the lot to move and place it to destination. After rotating, MCS detects available equipments the again.

Step 5: The lot will be pushed into equipment and processing.

Step 6: After finishing the processing, the lot unloads by equipment and release to intrabay.

Step 7: Intrabay set the turnout-sensor to determine whether the lot completes processing or not. When processing has finished, and then, it will enters to step 8, otherwise, it will be back to step 4.

Step 8: The lot transport from intrabay to interbay.

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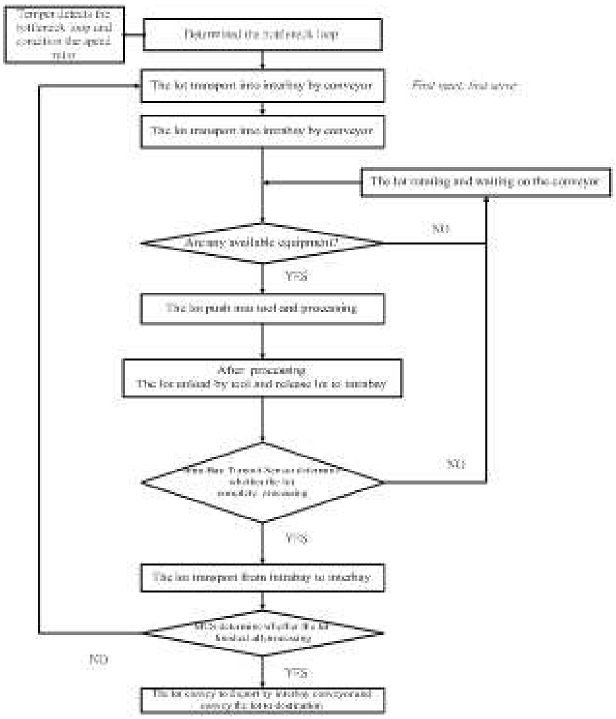

Fig. 4 Conveyor overall transport rules

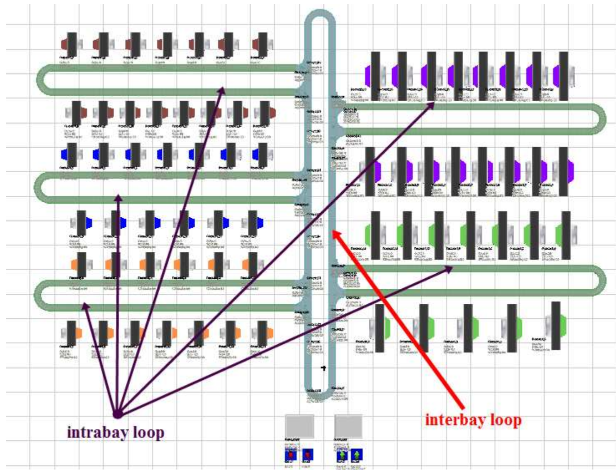

Fig. 5 Conveyor simulation model on Flexsim

Step 9: MCS determine whether the lot has finished all processing or not. (if yes enter step 10, or back to step 2.)
Step 10: The lot conveys to export by interbay conveyor and convey it to the destination.

3 Experiment Design

Our simulation models use the discrete-event simulation package from Canyon park technology center, USA. According to International SEMATECH 450 mm Guidelines [17] , the manufacturing process between 300 mm and 450 mm are similar. Therefore, this study combines some data from 300 mm to set up the 450mm fab environment [4,19,20]. In the authentic semiconductor manufacturing factory, an automatic material transporting is a very complex system, which is difficult to construct on the full simulation models. Hence, some assumptions are made to simplify the model without impacting the major purposes of this study.

The footprints of 450mm machines and 300mm ones are similar.

There is no failure and maintenance activity on the conveyor as well as equipment during the simulation horizon.

All lots' destinations are known and have been arranged in advance and processing machines executing one lot once.

The inter-arrival time of lots releasing to factory is assumed to be exponential distribution.

Each lot has 25 pieces of wafer; the equipment process time is 24 hours per day, 7 days per week, altogether runs 14 days with a pre-running time of 1 day.

The central aisle is 145 feet long, in the aisle is equipped with one-way track for an interbay, the central aisle connects 5 intrabays, and each intrabay aisle is 100 feet long. They are demonstrated in Figure 5.

The connection between interbay and intrabay are conveyors. The speed of conveyor is the same as OHT, which is set to 4.18 feet per second (ft/s) on basic 300 mm wafer fab, and the time for each loading/unloading is assumed to be 10 seconds.

All branches of interbay and intrabay set the turnout-sensor and speed-temper which showed in Figure 6 to differentiate the finished product or not and control the different speed of intrabay. And if the finished product is released to next equipment then others will be rotating around the intrabay loops. This study sets the input ratio in sinks, and instructs of sensor in machines, to transmit the realistic fab motions.

Figure 7 shows the different capacities of every intrabay in our simulation model, in order to show the obviously bottleneck resource, this study expands the capacity range between efficiency and bottleneck performance. The capacity of the first intrabay is 82 lots per hour; the second intrabay is 73; the third intrabay is 43; the fourth intrabay is 78 and the last intrabay is 88; obviously, the capacity of third intrabay is least, which states the exact situation of bottleneck. Hence, the third intrabay as the bottleneck loops which may change the speed of conveyor in the simulation models.

In the experiment design, this research considers two dominating control variables – the speed ratio of bottleneck loop and the bay loading ratio of bottleneck loop. The speed ratios are 4.18 ft/s, 8.16 ft/s, 16.72 ft/s

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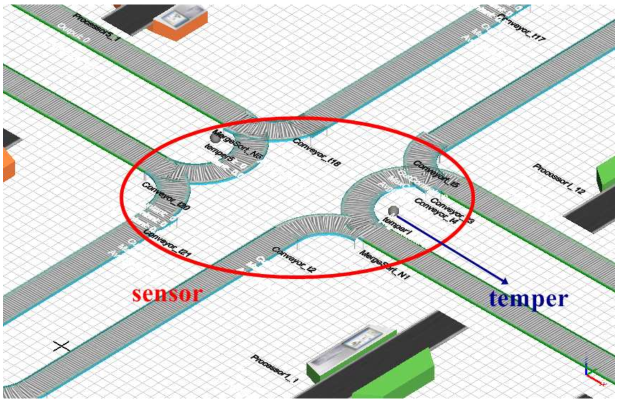

Fig. 6 Conveyor turnout-sensor and speed temper model

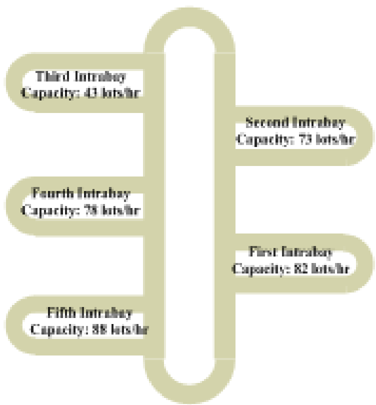

Fig. 7 Capacity of every intrabay

and 25.08 ft/s. The 4.18 ft/s is the speed of OHT in 300 mm foundry [19,20] . The limited speed of this research is 25.08 ft/s, contrast with the realistic conveyor speed limited, which is in the reasonable range. Bay loading ratio is defined as the average number of hourly input lots divided by the maximum number of hourly output lots of a bay. Five loading ratios 85, 90, 95, 100 and 105% of the design specification, are used in the simulation. Hence, the raw material input quantity = the seconds of an hours (bottleneck output lots per hour bay loading percentage product ratio percentage). The total number of simulation experiments performed is 4 (speed ratio) 5 (bay loading) 5 (replications) = 100. The simulation horizon is set to 14 days long with a one day pre-run for each experiment.

Flexsim is an object-oriented simulation system which can be applied on different industries. It's featured by hierarchy, inheritance and concurrency. These simulation models are implemented with the discrete-event package. In the execution simulation process, the Flexsim system can automatically record the result.

Average lot delivery time = conveyor transport time + product waiting time + loading and unloading time of conveyor = fixed time (theoretical moving time, included transport time, loading and unloading time) + variable time (waiting time and blocked time). The fixed time has theoretical value, and it can't be changed. But waiting and blocked time are variable. A good method can reduce the waiting and blocked time and therefore shrink the delivery time. Besides, there are some other indicators, like "the output of product", "the utilization of each tool type" and "idle of conveyor". But this research takes "average lot variable delivery time" as the main indicator of performance to demonstrate the result confirmation. The average lot variable delivery time is defined as below.

Average lot variable delivery time = conveyor transport time + product waiting time + loading and unloading time of conveyor - fixed time (theoretical moving time, included transport time, loading and unloading time) = variable time (waiting time and blocked time).

4 Experiment Results and Discussions

The detailed research results of different speed ratios of bottleneck loop and statistical test are demonstrated in this chapter. This research mainly improves the delivery time by increasing the bottleneck loop speed ratios. Comparing the standard speed 4.18 ft/s, which is the common speed of transportation OHT being used on all bays in 300 mm wafer fab, this research uses three higher speed ratios for study; double of 4.18 ft/s (8.36 ft/s), quadruple (16.72 ft/s) and six times speed of 4.18 ft/s (25.08 ft.s).

Table 1 shows the results of experiment. There are two clear and important observations. First, under a fixed bay loading, higher speed ratio gets higher improvement rate. Second, the average improvement rate of average lot variable delivery time increases against different bay loading; 7.76% for bay loading 85%, 8.13% for bay loading 90%, 8.80% for bay loading 95%, 9.84% for bay loading 100% and 4.52% for bay loading 105%. The bay loading 105% won't be discussed in our analysis because it represents that the input loading is over the productivity or transportations.

Table 2 depicts the results of statistical testing with pair data of speed 4.18 ft/s and 8.36 ft/s. Here the t value is 6.31, and the p value is 0. So there are significantly differences between the 4.18 ft/s and 8.36 ft/s. The speed 8.36 ft/s variable time can be significantly reduced. Moreover, according to Table 3, the t value is 5.99, and the p value is 0, for speed 4.18 ft/s and 16.72 ft/s variable time. The results mean that there are significantly differences. For Table 4, t he t value is 5.79, and the p value is 0 for speed 4.18 ft/s and 25.08 ft/s variable time. The results show that there are also significant differences as well. The higher speeds of bottleneck loop give a better

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Table 1 L ot variable delivery time in different bay loading

Bay Loading (%)	Speed Ratio (ft/s)	Average lot Variable Delivery Time (second)	Improvement Rate (%)
85%	4.18	931.62	—
85%	8.36	879.33	5.61
85%	16.72	875.92	5.98
85%	25.08	822.71	11.69
Average of 85%		877.39	7.76
90%	4.18	995.47	—
90%	8.36	924.78	7.10
90%	16.72	916.54	7.93
90%	25.08	902.28	9.36
Average of 90%		934.77	8.13
95%	4.18	1389.01	—
95%	8.36	1316.98	5.19
95%	16.72	1279.03	7.92
95%	25.08	1204.17	13.31
Average of 95%		1306.10	8.80
100%	4.18	3579.02	—
100%	8.36	3343.74	6.57
100%	16.72	3268.78	8.67
100%	25.08	3068.31	14.27
Average of 100%		3314.96	9.84
105%	4.18	33234.78	—
105%	8.36	32987.09	0.75
105%	16.72	32232.92	3.01
105%	25.08	29977.90	9.80
Average of 105%		32108.17	4.52

performance than the primary speed 4.18 ft/s, which means the higher speed increases the performance of all wafer bays significantly .

In addition, Table 5 shows, under various bay loadings, the average delivery time is 1,723.78 seconds for 4.18 ft/s, 1,616.21 seconds for 8.36 ft/s, 1,585.07 seconds for 16.72 ft/s, and 1,499.37 seconds for 25.08 ft/s. Which means the average lot variable delivery time decreases when the speed of bottleneck loop increases.

Table 5 Average lot variable delivery time under different speed ratio

Bay loading (%)	4.18 ft/s	8.36 ft/s	16.72 ft/s	25.08 ft/s
85	931.62	879.33	875.92	822.71
90	995.47	924.78	916.54	902.28
95	1389.01	1316.98	1279.03	1204.17
100	3579.02	3343.74	3268.78	3068.31
Average	1723.78	1616.21	1585.07	1499.37

unit: second Figure 8 demonstrates the average lots variable delivery time of different speed of bottleneck loop. When the speed of bottleneck loop is higher, the variable delivery time decreases. Under the total bay loading, compared with the speed 4.18 ft/s, the average lots variable delivery time of speed 8.36 ft/s is reduced by 6.24% (from 1723.78 s to 1616.21 s), the average lots variable delivery time of speed 16.72 ft/s is reduced by 8.05%(from 1723.78 s to 1585.07 s), the average lots variable delivery time of speed 25.08 ft/s is reduced by 13.02%(from 1723.78 s to 1499.37 s). As the results

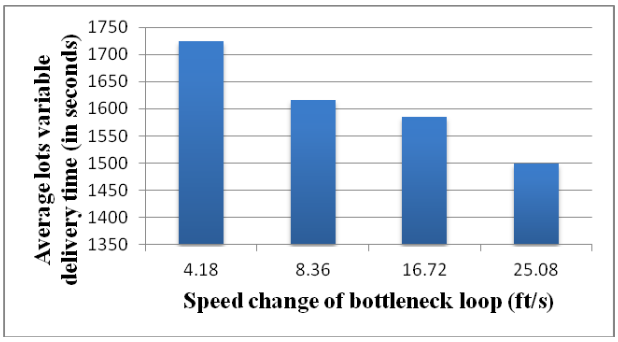

Fig. 8 Average lot variable delivery time in different speed of bottleneck loop

show, the higher speed control is useful to improve the performance of semiconductor fab.

5 Conclusions

The highly automatic material handling has become an inevitable trend; however, it may increase the complexity of control operations. With the advancement in wafer size, the equipment size will become larger, too. Therefore, constraint satisfaction has received increased attention in order to resolve planning and scheduling problems [21] . Accordingly, this research is to promote the transportation efficiency to get a better performance of all wafer factories rather than increase basic equipments. The purpose of this paper is to focus on the bottleneck of conveyor loops and provide effective transport dispatching rule for lots which will change the speed of bottleneck loops. The objective of this approach is to reduce product cycle time in 450 mm conveyor wafer fab.

This study gives diverse system configurations of loading ratios, and speeds of bottleneck loop. The results show the higher speed has the shorter variable time of lots in each environment. When increasing bay loadings, each time trends is upward for lot, and when increasing the speed of bottleneck loops, all time-trends are downward. When the conveyor resource is sufficient enough, changing the speed effectively to perform better in reducing lots variable times. The changing speed of bottleneck loop is very useful to streamline operations, such as scheduling, eliminating time delays in an automatic environment.

Future research may expand simulation model to a full-scale AMHS application. In fact, the fabs have various products and processing; thus, the more valuable goods, hot lot, can be simulated by applying priority dispatching rule as well as changing the speed. Also, it can prevent waiting time of lots, shortening the bottleneck blocks and increasing the performance of the wafer fabs.

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Table 2 Comparison between the speed 4.18 ft/s and 8.36 ft/s

Speed Ratio	N	Mean	STD Dev.	Mean	The Lower 95% Confidence	DF	t-value	p-value
4.18	20	1723.8	1113.6	248.9				
8.36	20	1616.2	1038.1	232.1				
4.18-8.36	20	98.8	81.9	18.3	78.1	19	6.3	0.0

Table 3 Comparison between the speed 4.18 ft/s and 16.72 ft/s

Speed Ratio	N	Mean	STD Dev.	Mean	The Lower 95% Confidence	DF	t-value	p-value
4.18	20	1723.78	1113.55	248.99				
16.72	20	1585.07	1010.26	225.90				
4.18-16.72	20	138.71	103.53	23.15	98.68	19	5.99	0.00

Table 4 Comparison between the speed 4.18 ft/s and 25.08 ft/s

Speed Ratio	N	Mean	STD Dev.	Mean	The Lower 95% Confidence	DF	t-value	p-value
4.18	20	1723.78	1113.55	248.99				
25.08	20	1499.37	940.76	210.36				
4.18-25.08	20	224.41	173.32	38.76	157.40	19	5.79	0.00

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