Proceedings of the 2002 Winter Simulation Conference
E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, eds.

OPERATIONAL MODELING AND SIMULATION OF AN INTER-BAY AMHS IN SEMICONDUCTOR WAFER FABRICATION

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ABSTRACT

This paper studies the operational logic in an inter-bay automated material handling system (AMHS) in semiconductor wafer fabrication. This system consists of stockers located in a two-floor layout. Automated moving devices transfer lots between stockers within the same floor (intra-floor lot transfer) or between different floors (inter-floor lot transfer). Intra-floor lot-transferring transports use a two-rail one-directional system, whereas inter-floor lot-transferring transports use lifters. The decision problem consists of selecting rails and lifters that minimize average lot-delivery time. Several operation rules to deliver lots from source stocker to destination stocker are proposed and their performance is evaluated by discrete event simulation.

1 INTRODUCTION

Many wafer fabs have been laid out as bays, and each bay is supplied with stockers (Wein 1988). In a large wafer fab, inter-bay and intra-bay automated material handling systems (AMHS) have been widely used to transfer lots. In particular, the inter-bay AMHS moves lots between stockers, whereas intra-bay AMHS moves lots between stockers and tools, or between tools within the same bay.

Most companies are interested in reducing the average cycle time in order to increase productivity and improve on-time delivery. In material handling problems, average cycle time is affected by the time that lots wait in queue for transports and the moving time. By definition, the lot-delivery time is the period from when lots send a request for transport until the lot is transferred to its final destination (Mackulak and Savory 2001).

In an inter-bay AMHS, the problem of reducing the average delivery time is complex. There are multiple decisions to consider. For example, in a one-floor layout, the decision problem is to optimize the delivery time of lots between stockers. However, in a multiple-floor layout, the decision problem becomes optimizing the delivery time of lots between stockers on the same floor and between stockers on different floors.

2 PROBLEM DESCRIPTION

The inter-bay AMHS under study consists of stockers, lifters, and rails distributed in a two-floor layout. Figure 1 illustrates the location of stockers and lifters. Photo and etch operations are processed on the first floor. Diffusion and thin film operations are processed on the second floor. Inner and outer rails are used for moving lots on the same floor. Lifters are used for moving lots between the floors.

Figure 2 shows the inside of a stocker (Cardarelli and Pelagagge 1995). Stockers are equipped with an inside track-robot (rack-master), two devices (TFE) for lot ex-

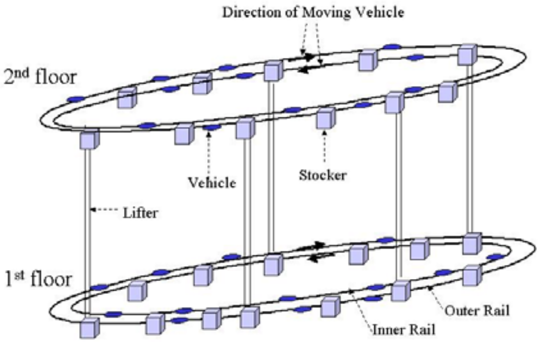

Figure 1: Brief Illustration for Inter-Bay System

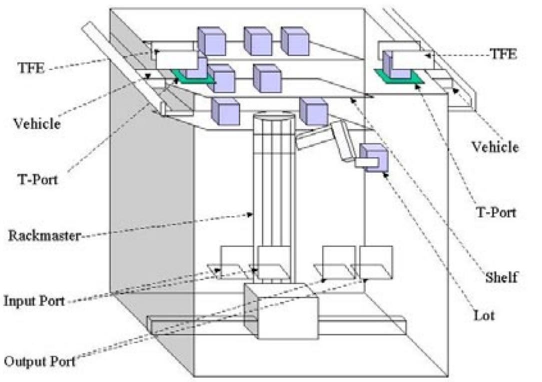

Figure 2: Inside of a Stocker

change with transports, and two devices (T-Port) for lot exchange between TFE and rack-master. In addition, some stockers include a lifter.

The specific characteristics of the system under study are as follows:

1. There are many stockers in the first and second floor, respectively.
2. There are two-unidirectional rails per floor.
3. There are five bi-directional lifters in the system.
4. There are many transports per rail on the first and second floors, respectively. The control logic is vehicle-driven. In other words, transports on each rail move continuously, checking for lots ready to be moved in the stockers. In the case that a vehicle is blocked or stops for loading or unloading lots, the vehicle located in the previous control point becomes blocked.

As was mentioned above, there are two decision problems related to lot-delivery time. The first problem consists of selecting which rail to use, the inner or outer rail. Delivery times are dependent on several factors. For example, they depend on the distance between source and destination stockers. This distance can be different depending on the rail used. They also depend on the number of lots waiting to be moved per rail. We call this problem the *rail selection problem*. The second decision problem to consider is the selection of which lifter to use in case of an inter-floor transfer. As in the rail selection problem, the distance between stocker and lifter, and the number of waiting lots in the lifter are factors that affect the selection of the lifter. We call this problem the *lifter selection problem*.

The logical lot-flow sequence for the intra-floor movement is as follows:

1. Ready lot arrives to stocker
2. Inner or outer rail is selected
3. Lot waits for vehicle in the T-port of the stocker
4. Lot is loaded into the empty vehicle
5. Lot is moved to destination stocker
6. Lot is unloaded into the T-port of the destination stocker

The logical lot-flow sequence for inter-floor movement is as follows:

1. Ready lot arrives to stocker.
2. Lifter is selected
3. Inner or outer rail is selected
4. Lot waits for vehicle in the T-port of the stocker
5. Lot is loaded into the empty vehicle
6. Lot is moved to lifter stocker
7. Lot is unloaded into the T-port of the lifter stocker
8. Lot is moved by the lifter
9. Repeat intra-floor movement logic

3 OPERATION LOGICS FOR RAIL AND LIFTER

Several simple dispatching rules for rail and lifter selection are considered. Since there are many unpredictable factors, it is difficult to find the optimal transfer time. Therefore, we concentrate on developing dispatching algorithms for each problem to minimize delivery time.

The notations used in the proposed algorithms are listed below:

$d_{x,y}^{j}$: Distance between source stocker x and destination stocker y in the same floor when a lot is transferred by j rail, where j could be inner (I) or outer (O).

d_{x}^{k} : Minimum distance between source (or destination) stocker x and lifter k.

NWR^{j} : Number of waiting and transfer lots on j rail at decision time point.

NWL^l : Number of waiting and transfer lots on *l* lifter in the floor having source stocker at decision time point.
LS : Set of lifter index

Four dispatching algorithms are proposed for the Rail Selection Problem:

1. Select the rail having the shorter distance from the source stocker to the destination stocker. That is, if $d^I_{x,y} \ge d^O_{x,y}$, then select outer rail, otherwise select inner rail.
2. Select the rail having the fewest number of waiting lots when the lot arrives to the stocker. That is, if $NWR^I \ge NWR^O$ then select outer rail, otherwise select inner rail.
3. Combine 1 and 2. That is, find rail with the minimum distance between source and destination stocker. If the number of waiting lots on this rail is greater than a predefined value *KR*, then the other rail is selected. That is, find rail having $\min_{j \in \{I,O\}} \left\{ d^j_{x,y} \right\}$ (we call this rail j*), if $NWR^{j*} < KR$, select this rail; otherwise, select the other rail.
4. Select rail at random.

Four dispatching algorithms are proposed for lifter selection problem. These are very similar to those of the rail selection problem.

1. Select the lifter having the shortest distance from source stocker to lifter. That is, select the lifter *k* having $\min_{k \in LS} \left\{ d^k_x \right\}$.
2. Select the lifter having the fewer number of waiting lots at the moment that the lot arrives to the stocker. That is, select the lifter *l* having $\min_{l \in LS} \left\{ NWL^l \right\}$.
3. Combine 1 and 2. That is, find lifter with the minimum distance between source stocker and lifter. If the number of waiting lots on this lifter is greater than a predefined value *KL*, then another lifter is selected. Repeat until lifter is finally selected. That is, find lifter *k** having $\min_{k \in LS} \left\{ d^k_x \right\}$, if $NWL^{k*} < KL$, select lifter *k**, otherwise find lifter *k*** having $\min_{k \in LS - \{k*\}} \left\{ d^k_x \right\}$, if $NWL^{k**} < KL$, select lifter k**, etc. If $NWL^k \ge KL$ for all *k* lifters, select lifter having $\min_{l \in LS} \left\{ NWL^l \right\}$.
4. Select lifter at random.

4 SIMULATION MODELING

A simplified simulation model of the system under study was built using the event orientation of SLAM (Pritsker 1995). The purpose of using simulation modeling is to evaluate the performance of the rail and lifter selection rules in terms of average delivery time. The results represent the relative performance of a simulated fab as a function of the input parameters.

The assumptions used in the model are as follows:

Physical Assumptions

1. There are 8 and 6 stockers in the first and second floor, respectively.
2. Stockers have unlimited capacity.
3. There are two lifter stockers in each floor, LA and LB.
4. The time for moving a lot in a lifter is 81 seconds.
5. The sequence in the first floor is as follows:

   LA-S1-S2-S3-LB-S4-S5-S6-S7-S8-LA

   The sequence in the second floor is as follows:

   LA-S9-S10-S11-LB-S12-S13-S14-LA

   where, S_i represents stocker i.
6. There are 8 and 6 transports per rail in the first and second floor, respectively.
7. The distance between stockers is 10 meters.
8. The speed of transports is constant.
9. The average speeds of transports are equal to 1.33 m/s and 0.50 m/s in the first and second floor, respectively.
10. Transports and lifters carry only one lot at any time.
11. The times required to load and unload the lot were 30 seconds each.
12. Only one vehicle occupies one control point on the rail at a time.

Modeling Assumptions

13. Lots are generated at random on each stocker.
14. The fab runs 24 hours a day 7 days a week.
15. The value for the number of lots waiting threshold *K* is 4.
16. No vehicle and lifter downtimes are implemented.
17. The intra-bay AMHS is not simulated.

The simulation model is valid if the movement control logic in the simulation model mimics the logic used in the actual system (Mackulak and Savory 2001). Closed interaction with experts in the system described in Section 2 allowed the simulation analysts to implement the same control logic used in the real system in simulation code. The system experts verified that the control logic in the simulation model was identical to the control logic in the real system.

5 SIMULATION RESULTS

The performance of the decision rules proposed in Section 3 was tested for various proportions of intra-floor/inter-floor lot transfer. For example, a 50%/50% proportion means that 50% of the lots are delivered to stockers within the same floor, and the other 50% are delivered to stockers in the other floor. The reason for doing this analysis was to determine if there was a significant advantage of one decision rule over the others, in terms of average delivery time, at different flow patterns. Table 1 summarizes the cases that were studied.

Table 1: Proportions of Intra-Floor/Inter-Floor Transfer under Study

Case	Percentage of intra-floor lot transfer	Percentage of inter-floor lot transfer
1	50%	50%
2	75%	25%
3	90%	10%

For each case shown in Table 1, a full factorial design of experiments was conducted by changing the rail and lifter decision rules. Therefore, 16 different scenarios were considered per case. 10 replications for each scenario were run. A total of 110,000 delivery times were collected from each simulation replication. System variables were cleared after the first 10,000 observations.

5.1 Results for 50%-50% Intra-Floor/ Inter-Floor Lot Transfer

Table 2 lists the 16 scenarios studied in the 50%-50% intra-floor/inter-floor lot transfer case. The codes used in the second and third columns follows the same order given in Section 3. For the reader's convenience, the codes for rail and lifter selection rule are repeated:

1. Minimum distance
2. Minimum number of waiting lots
3. Minimum distance and minimum number of waiting lots
4. Random selection

Table 1 also includes the results of the multiple range test using the LCD reference method at α=0.05 (Montgomery 1997). Results are presented in the form of homogenous groups. At this proportion rate, a large number lots is transferred between floors. The travel time of lots in the lifter from one floor to the other is relatively higher than moving lots between any two stockers within the same floor. Therefore, the number of lots waiting to use the lifter is higher. Notice that the lowest average delivery times and variance are for scenarios 2 and 10. The decision rule selects the rail that minimizes transfer distance and selects the lifter with the lowest number of waiting lots in its queue. Scenarios 3 and 11 give the second lowest delivery times. In this case, the lifter selection rule minimizes distance and the number of waiting lots in queue. Table 1 also shows that the average delivery time and variance are high for scenarios that use lifter selection logic 1 and 4.

Table 2: Simulation Results for the 50%-50% Intra-Floor/Inter-Floor Lot Transfer Case

Scenario	Rail Selection Rule	Lifter Selection Rule	Average Delivery Time	Std. Dev.	Homogenous Groups
2	1	2	203.182	1.976	x
10	3	2	203.182	1.976	x
3	1	3	226.735	2.410	x
11	3	3	226.748	2.403	x
4	1	4	249.164	3.499	x
12	3	4	249.164	3.499	x
14	4	2	250.081	2.037	x
6	2	2	250.414	2.061	x
15	4	3	274.812	2.441	x
7	2	3	277.213	2.446	x
1	1	1	277.779	8.688	x
9	3	1	277.779	8.688	x
16	4	4	291.868	3.521	x
8	2	4	293.563	3.159	x
13	4	1	325.834	8.997	x
5	2	1	328.245	9.049	x

5.2 Results for 75%-25% Intra-Floor/ Inter-Floor Lot Transfer

Table 3 shows the scenarios for the 75%-25% intra-floor /inter-floor lot transfer case. The lowest average delivery times are again for scenarios 2 and 10. However, for this case, the differences in delivery times between this homogenous group and the next three groups are small. The commonality between these groups is that they use rules 1 and 3 for rail selection. These results imply that as the intra-floor lot-transferring transports are more utilized, minimizing the transfer distance becomes more important. At this intra-floor/inter-floor proportion, the lifter is less utilized. Therefore, it can be noticed that the lifter decision rule slightly affects the delivery times.

Table 3: Simulation Results for the 75%-25% Intra-Floor/Inter-Floor Lot Transfer Case

Scenario	Rail Selection Rule	Lifter Selection Rule	Average Delivery Time	Std. Dev.	Homogenous Groups
10	3	2	104.005	0.601	x
2	1	2	104.012	0.412	x
3	1	3	105.318	0.543	x
11	3	3	105.318	0.562	x
1	1	1	105.561	0.697	x
9	3	1	105.561	0.469	x
12	3	4	107.717	0.620	x
4	1	4	107.729	0.626	x
14	4	2	138.380	0.601	x
6	2	2	138.452	0.408	x
16	4	4	141.082	0.543	x
15	4	3	141.298	0.560	xx
13	4	1	141.694	0.680	x
8	2	4	142.533	0.434	x
7	2	3	143.108	0.545	x
5	2	1	143.451	0.629	x

Table 4: Simulation Results for the 90%-10% Intra-Floor /Inter-Floor Lot Transfer Case

Scenario	Rail Selection Rule	Lifter Selection Rule	Average Delivery Time	Std. Dev.	Homogenous Groups
11	3	3	66.4374	0.180	x
3	1	3	66.4375	0.201	x
9	3	1	66.4412	0.178	x
1	1	1	66.4413	0.199	x
10	3	2	67.2648	0.256	x
2	1	2	67.2649	0.276	x
12	3	4	67.5119	0.257	x
4	1	4	67.5119	0.255	x
14	4	2	95.0985	0.180	x
15	4	3	95.0985	0.201	x
16	4	4	95.1815	0.178	x
13	4	1	95.2777	0.199	x
6	2	2	95.5008	0.225	x
8	2	4	96.2949	0.270	x
5	2	1	96.5376	0.270	x
7	2	3	96.5409	0.231	x

5.3 Results for 90%-10% Intra-Floor/ Inter-Floor Lot Transfer

Table 4 lists the scenarios for the 90%-10% intra-floor/inter-floor lot-transfer case. This case is characterized by lower utilizations of lifters and higher utilizations of intra-floor lot-transferring transports. It was inferred from the simulation results that using rail decision rules 1 or 3 give the lowest average delivery times. Scenarios 1, 3, 9, and 11 are part of the best homogenous group. However, notice that scenarios 2 and 10 belong to the third lowest homogenous group. The difference between this group and the best group is small.

6 CONCLUDING REMARKS

The inter-bay AMHS is a complex system, characterized by stochastic event occurrences. As was stated above, the delivery time is composed of the time that lots wait in stockers for transports plus transfer time. Minimizing the average delivery time will also minimize average cycle time. This paper proposes four rail decision rules and four lifter decision rules to minimize average transfer time. Simulation modeling was used to evaluate the decision rules. After comparing the combination of rail and lifter selection rules at different proportions of intra-floor/inter-floor lot transfer, it was concluded that scenarios 2, 3, 10, and 11 gives lower average delivery times consistently throughout the three cases studied. In other words, the decision rule that selects the rail with the minimum travel distance between source and destination stocker, or the decision rule that selects the rail with the minimum travel distance between two stockers and the minimum number of lots waiting for a vehicle, should be used. The decision rule that selects the lifter with the minimum number of lots waiting for the lifter, or the decision rule that selects the lifter with the minimum travel distance between stocker and lifter and the minimum number of lots waiting for the lifter, should be used.

7 FUTURE WORK

For future research, different system conditions will be tested. These conditions include more stockers, lifters, and transports. Different arrival patterns will also be included in the study. As a parallel work, other rail and lifter selection rules will be implemented and evaluated.

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