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A new concept of the dynamic connecting transport automated material handling system (AMHS) is proposed. This paper analyses the performance of the number of vehicles in a dynamic connecting transport AMHS in a simplified 300 mm wafer fab. Discrete-event simulation models are developed in *e*-M Plant^{TM} to study the system performance. To avoid congestion or idle time in the intrabay system, the control of the upper limit or the lower limit on the number of vehicles can be the feasible solution. Thus, four strategies are identified and their performances are also investigated. In addition, several different operation environments such as the flow rate and the product-mix are used to investigate the performance of the dynamic connecting transport AMHS.

Keywords: Dynamic connecting transport; Automated material handling system; Simulation

1. Introduction

An AMHS in semiconductor manufacturing optimises productivity, improves equipment utilisation and ergonomics, and reduces particle contamination and vibration shock to the wafers. Furthermore, fewer operators are necessary. Nevertheless, the savings from modest staff reductions can be offset by the cost of equipment and systems, but automation can generate positive effects on overall equipment effectiveness (OEE), yields, development time, ramp time, and cycle time. These benefits should be substantially greater than those that are accrued from staff reductions. Full-fab automation includes two key elements: an automated material handling system (AMHS) that moves WIP from one process equipment to another, and factory management software that converts the flow of data into information, thus transforming the fab into an intelligent manufacturing environment (Chase *et al.* 2000).

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Research into AMHS is generally conducted with simulation analysis, and is directed at track layout, performance analysis, and management issues such as dispatch rules for vehicle control, transport types, the number of vehicles required and the provision of control zones and buffers. Pierce and Stafford (1994) studied three types of interbay layout by simulation: spine, perimeter, and custom track systems. The simulation results showed that the custom layout had a 16% more efficient delivery time than the spine layout, and that the perimeter layout had the worst performance in terms of delivery time, vehicle utilisation, and track length requirement. The most practical approach to enhance interbay AMHS performance is to minimise the distances between stockers by using a custom track layout with turntables. Kurosaki *et al*. (1997) and Pillai *et al*. (1999) addressed the linking of interbay and intrabay track options for a 300 mm fab layout. They found that the delivery time of isolated and linking track systems was highly dependent on the traffic type. Peters and Yang (1997) presented a combination of a space filling curve and network flow procedures that could efficiently and effectively solve the integrated layout and material handling system design problem for both the spine and perimeter configurations. Mackulak and Savory (2001) compared the intrabay layout of two automated material handling systems. The results showed that the average delivery time that was produced by the distributed system was always less than the value that was produced by the centralised system. Ting and Tanchoco (2001) used an analytical approach to develop optimal single-spine and double-spine overhead track layouts and minimize travel distance. They also indicated that the simplicity, track length, and flow distances of the spine layout made it suitable for 300 mm fab. Wang and Lin (2004) presented the behaviour of the interarrival time for all stockers from a real data set to verify the assumption of the simulation model. They found that for most stockers interarrival times belong to the exponential or Weibull distribution. Also, the simulation results show that the number of vehicles significantly affects the average delivery time and the average throughput.

When the layout and material handling equipment have been determined, performance analysis can be used to evaluate AMHS design alternatives. Cardarelli and Pelagagge (1995) used discrete event simulation to examine system performance with such factors as stocker capacity, production planning and scheduling, and system management. They showed that the storage capacity distribution along the interbay track is important in maintaining AMHS performance. Mackulak *et al*. (1998) investigated the relationship between the vehicle carrying capacity and the tool batch size of an intrabay system. The results showed that vehicle capacity had the most significant effect on average delivery time. Paprotny *et al*. (1999) compared continuous flow transport (CFT) and overhead monorail vehicles (OMVs). They found that the delivery time of OMVs was half that of the cost-effective CFT system, but the standard deviation of OMV was almost 10 times larger than that of the CFT system. Campbell *et al*. (2000) used the simulation models to show that the published international SEMATECH vision of a fully automated factory could sufficiently support the production requirements of a 300 mm factory.

AMHS management, such as cost evaluation and vehicle control, has emerged as a new research area. Murray et al. (2000) performed a financial evaluation of manual and AMHS systems. Through sensitivity analyses of interest rates, wafer start rates per month, price per die, and yield percentages they showed that the net present value (NPV) of AMHS was favourable to that of the manual handling system. Bahri and Gaskins (2000) introduced a logistic algorithm to balance the flow of traffic to and from the load/unload nodes of an interbay delivery system. A simulation model of this algorithm demonstrated up to 30% improvement in lot delivery times. Automatic guided vehicle (AGV) dispatching is widely addressed in the literature on the AMHS of job shop manufacturing. Lin *et al.* (2001) employed AGV dispatch rules to evaluate the system performance of a double loop interbay system. They indicated that the dispatch rules had significant effects on delivery time. The simulation results suggested that a combination of the shortest distance (SD) with the nearest vehicle (NV) and first-encounter-first-serve (FEFS) outperformed the other rules. However, most studies only examined the interbay system or the intrabay system. To improve the performance of AMHS in a 300 mm wafer fab, Lin *et al.* (2003a) proposed the connecting transport concept, using a different type of vehicle between bays than within bays and a single system of interconnected lines. Then, Lin *et al.* (2003b) presented the relative performance of the connecting transport AMHS with *e*-M Plant^{TM} simulation (2000). The results showed that the combination of vehicle types had a significant effect on average travel time, throughput, and vehicle utilisation. When travel time is the major concern, the suitable method is the combination of Type A and Type D vehicles. When throughput is the major concern, the suitable method is the combination of Type A and Type C vehicles. When vehicle utilisation is the major concern, the suitable method is the combination of Type A and Type B vehicles. However, no one method outperformed the others in all operational scenarios. Recently, Lin *et al.* (2004) proposed a virtual vehicle in the connecting transport AMHS that can improve the task of moving wafers between bays and within each bay by a single system with interconnected lines.

In order to improve the performance of the connecting transport AMHS in a 300 mm wafer fab, the vehicle control such as the zone control, the deadlock issue and the empty vehicle management must be considered. In this study, a dynamic connecting transport AMHS is proposed and the performance of the number of vehicles is also investigated. The description of a simplified 300 mm AMHS system and the dynamic connecting transport AMHS are presented in the next section. The simulation models and experiments, followed by a discussion of the simulation results, are presented in sections 3 and 4. Conclusions are made in the final section, along with suggestions for further research.

2. System descriptions and the dynamic connecting transport AMHS

For this study, a 300 mm wafer fab in Taiwan is simplified and represented by a total of 123 tools. Figure 1 depicts a representative layout that contains a single loop of an interbay system, eight intrabay systems, and 16 stockers. In general, the tools in a wafer fab can be categorized into six areas: diffusion, etching, implant, lithography, thin-film, and inspection. The layout in figure 1 is also categorised into four areas, in which the etching area occupies one and a half bays, the thin-film area occupies two and a half bays, the lithography area occupies two bays, and the implant area occupies two bays. The track in the interbay or intrabay system can have the short cut or by pass zone. Figures 2 and 3, respectively, depict that there are five types of input operations and three types of retrieve operations for the lot movement between tools. The detailed discussion of the input operation and retrieve operation can be found in Lin *et al.* (2004).

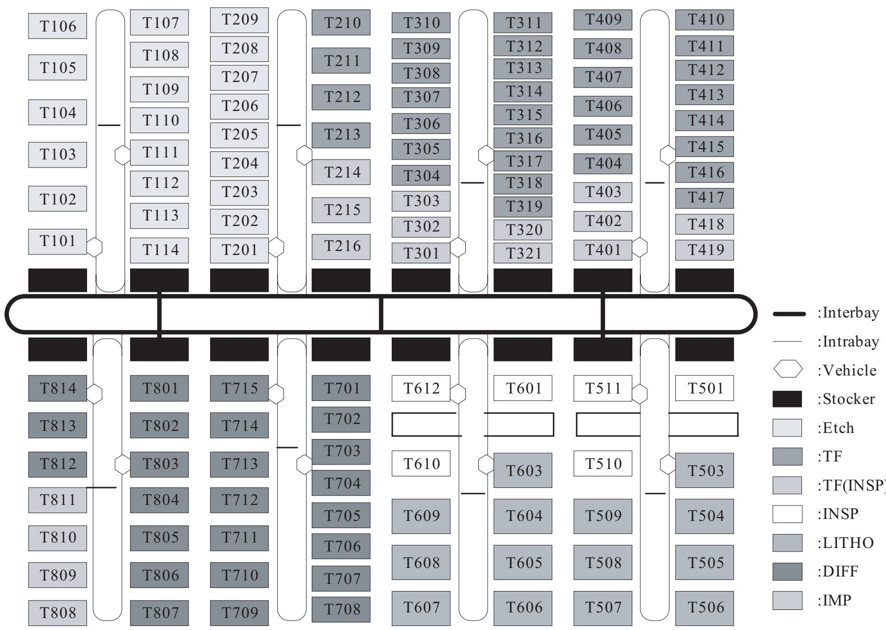

Figure 1. A simplified layout of an AMHS in a 300 mm wafer fab.

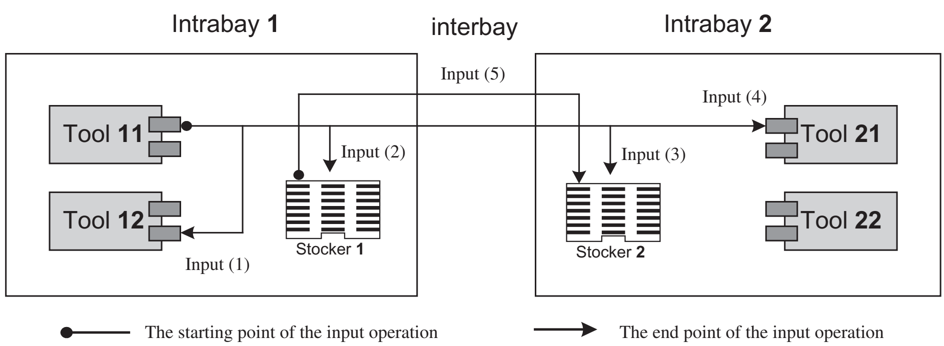

Figure 2. Five different types of the input operation.

Some examples of the wafer movement information are shown in table 1, and the from–to distance and arrival rate between tools are shown in table 2. The arrival rate of the lots is defined as the quantity per hour and this information can be retrieved from the manufacturing execution system (MES). For instance, the lot that was coded by AK01-A enters the process tool Exxx-01 in the diffusion bay at 23:07:44 on 02/25/04, and finished the processing and left at 23:10:21 on the same day. The lot must arrive by 23:45:47 on 02/25/04 at the next destination tool, Sxxx-06 in the thin-film bay, and leave at 00:03:19 on 02/26/04. Thus, using the data from manufacturing executive system (MES), the arrival rate can be determined.

The vehicle used is the overhead hoist transporter (OHT), which holds the front open unified pod (FOUP) by its top flange. Lin *et al.* (2003a) proposed the concept of connecting transport. The connecting transport AMHS enables the use of a different

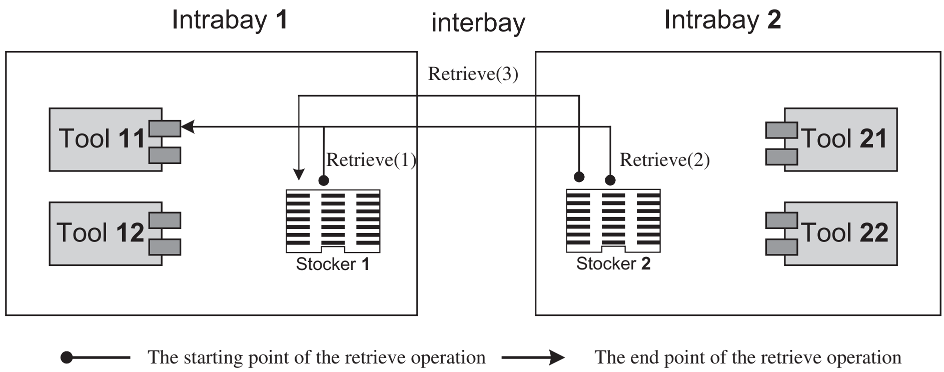

Figure 3. Three different types of the retrieve operation.

Table 1. Some examples of information about movement of lots.

Lot	Part	Pieces	Start	Finish	Stngrp	Stnfam	Stn	Due
AK01-A	AK01-A_5	25	02/25/04 23:07:44	02/25/04 23:10:21	DIFF	Exxx	Exxx-01	03/21/04
AK01-A	AK01-A_5	25	02/25/04 23:45:47	02/26/04 00:03:19	TF	Sxxx	Sxxx-06	03/21/04
AK01-A	AK01-A_5	25	02/26/04 00:36:56	02/26/04 01:01:24	LITHO	Ixxx	Ixxx-03	03/21/04

Table 2. From–to table giving arrival rate (lot moves/hours) between tools.

	T101	T102	T103	T104	T105	...	T201	T202	T203	...	Total
T101		87.5	87.5	87.5	327	...	1.5	2.875	2.875	...	1389.75
T102	87.5		87.5	87.5	327	...	1.5	2.875	2.875	...	3974
T103	87.5	87.5		87.5	327	...	1.5	2.875	2.875	...	2499
...	...	...	...	...	...	...	...	...	...	...	...
T201	1.625	1.625	1.625	1.625	7.5	...		0.25	0.25	...	672.5
T202	7.75	7.75	7.75	7.75	55.5	...	0		35	...	217
...	...	...	...	...	...	...	...	...	...	...	...
Total	3971	2495	395.66	395.66	395.66	...	671.5	208	216	...	

type of vehicle between bays than within bays and an interbay transportation line linking the intrabay transportation lines to form a single integrated material handling system. In this connecting transport system, the time that is spent waiting for an empty vehicle is effectively eliminated, and the WIP level can be reduced. Here, a dynamic connecting transport AMHS is proposed for solving the traffic congestion, blockage, deadlock and system idle. The proposed model is different from another model with vehicle travel ambit considered in Lin *et al*. (2003a), where the ability of a vehicle to travel to an intrabay depends on vehicle type. In this model, a vehicle may travel throughout the intrabay and interbay system, but its movement may be restricted when the number of vehicles in an area is at the upper limit for that area or the number of vehicles in an area is at the lower limit needed in that area.

A zone control strategy is used to make sure of collision free. In zone control, a travelling vehicle will stop whenever another vehicle is detected in the zone ahead. That is, an intelligent vehicle control system should actively push the empty vehicle away to keep the guide path available for the loaded vehicle. A deadlock that is a conflict condition between a tool and vehicles may happen. A feasible solution for such situation is that the loaded vehicles send the lot to the stocker for temporary inventory. In order to avoid congestion or idle time in the intrabay system, the control of the upper limit or the lower limit of the number vehicles can be the feasible solution. Thus, four strategies are identified and they are given by:

S1: Each intrabay without the upper and lower limits of the vehicle numbers.
S2: Each intrabay without the upper limit of the vehicle numbers and with the lower limit of the vehicle numbers.
S3: Each intrabay with upper limit of the vehicle numbers and without the lower limit of the vehicle numbers.
S4: Each intrabay with the upper and lower limits of the vehicle numbers.

From the above discussion, if the movement task such as vehicle searches lot (VSL) or lot searches vehicle (LSV) reaches the upper limit of vehicle number or the lower limit of vehicle number, then the movement task must be reinitiated. Four examples (see figures 4–7) are used to illustrate the characteristics of a dynamic connecting transport AMHS.

Example 1: A lot from tool M22 in intrabay 2 requests the movement to another tool in intrabay 8 and initiates the LSV. It is found that empty vehicle OHT1 from interbay system can finish this task. Suppose that the upper limit on the number of vehicles in intrabay 2 is six, vehicle OHT1 approaches this intrabay 2 and finds that six vehicles already exist in that intrabay. Thus, vehicle OHT1 cannot enter intrabay 2 and reinitiates the VSL. Also, the lot in tool M22 reinitiates the LSV.

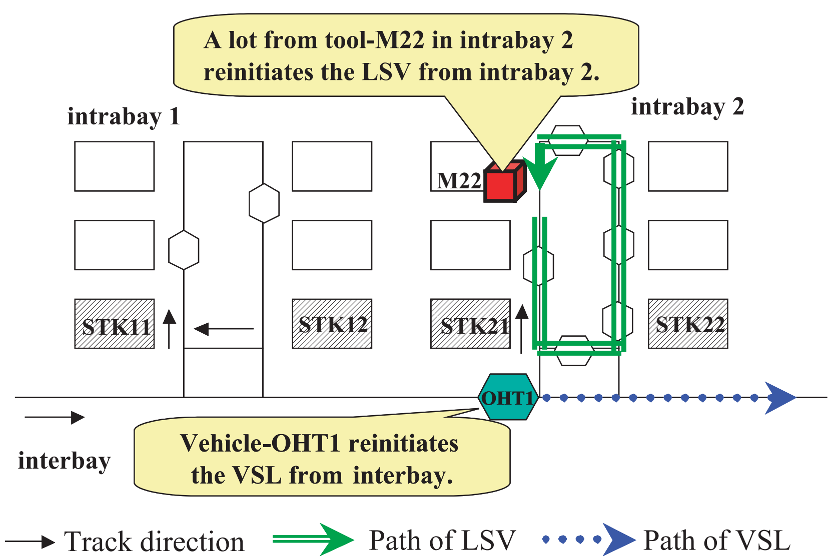

Figure 4. reLSV and reVSL for example 1.

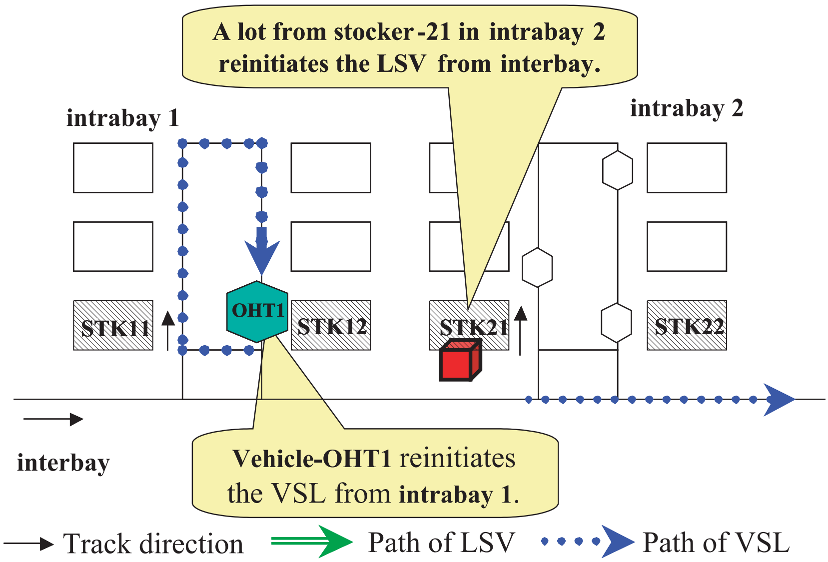

Figure 5. reLSV and reVSL for example 2.

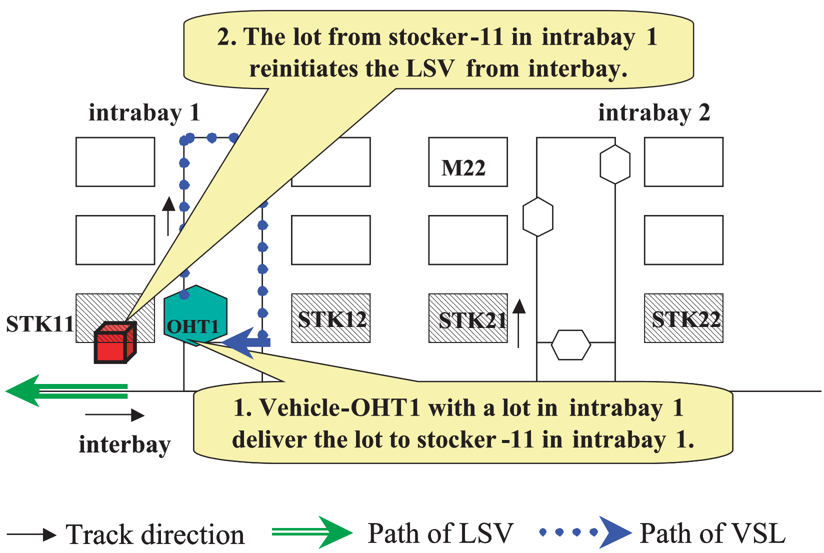

Figure 6. The movement for example 3.

Example 2: A lot from stocker 21 in intrabay 2 requests the movement to the tool in intrabay 1 and initiates the LSV. It is found that empty vehicle OHT1 from intrabay 1 can finish this task. If the lower limit on the number of vehicles in intrabay 1 is one and vehicle OHT1 is in intrabay 1, then the lot from stocker 21 cannot be moved by a vehicle. Thus, vehicle OHT1 cannot go out from intrabay 1 and reinitiates the VSL. Also, the lot in stocker 21 reinitiates the LSV.

Example 3: If vehicle OHT1 is in intrabay 1 with a lot that needs to be delivered to tool M22 in intrabay 2 and the lower limit on the number of vehicles in intrabay 1

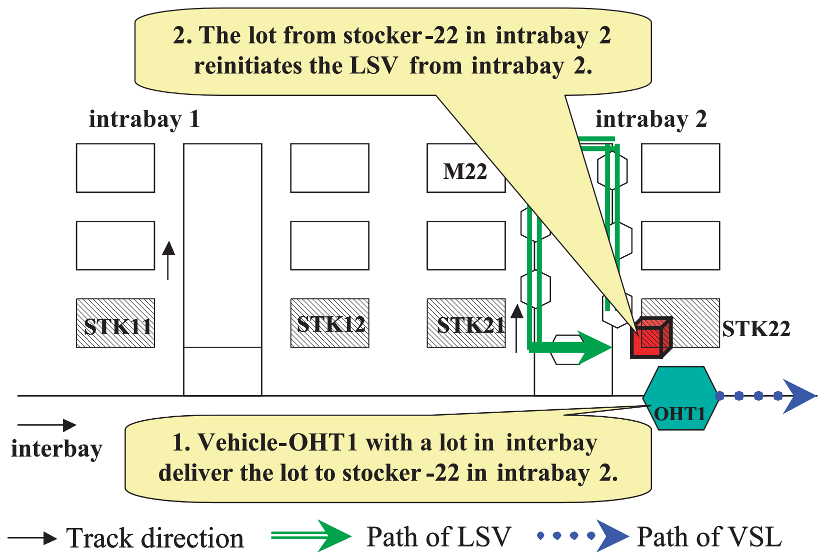

Figure 7. The movement for example 4.

is one, then vehicle OHT1 cannot leave intrabay 1. This particular lot will be delivered to stocker 11 in intrabay 1 and this lot will reinitiate the LSV.

Example 4: Assume that the vehicle OHT1 with a lot is in the interbay system and that the lot has to be delivered to tool M22 in intrabay 2. Suppose that the upper limit on the number of vehicles in intrabay 2 is six and the vehicle OHT1 approaches intrabay 2 and finds six vehicles in that intrabay. In this situation, vehicle OHT1 cannot enter intrabay 2. This particular lot will be delivered to stocker 22 in intrabay 2 and this lot will reinitiate the LSV.

A simple mathematical model by Maxwell and Muckstadt (1982) can be employed to determine the lower limit of the vehicle numbers for each intrabay. This approach considered the total loaded vehicle travel time and the total empty vehicle travel time and the mathematical model is given as follows.

1. Total loaded vehicle travel time: $T_l = \sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij} l_i + \sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij} u_j + \sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij} t_{ij}$ where x_{ij} = the delivery requirements from tool i to tool j; l_i = the load time at tool i; u_j = the unload time at tool j; t_{ij} = the travel time from tool i to tool j.
2. Total empty vehicle travel time: The model's objective function will measure the total travel time for empty vehicles moving between tools. That is, $T_e = \text{Min} \sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij} x_{ij}$ where $\sum_{j=1}^{n} x_{ij} = a_i$ if the net flow (NF) for tool i is non-negative, $-\sum_{k=1}^{n} x_{ki} = b_i$ if the net flow into tool i is negative. It is easy to see that the above problem is a simple transportation problem of linear programming. The solution indicates how many vehicle trips should be made with empty vehicles between tools i and j. Thus, the total travel time is $T_l + T_e$, and h hours are available on the shift per vehicle, then the minimum number of vehicles is given by

$$N = \left[\frac{T_l + T_e}{h}\right],$$

where $\lceil z \rceil$ is the smallest integer greater than or equal to z. Moreover, to assure that N is larger than the minimal number of vehicles needed, an upper bound for the number of vehicles is given by

$$N = \left\lceil \frac{3 \times T_l + 2 \times T_e}{h} \right\rceil.$$

3. Simulation models and experiments

Discrete event simulation models were used to evaluate the performance of the number of vehicles in connecting transport automated material handling system (AMHS) in a wafer fab. The models were built and executed using *e*-M Plant^{TM} simulation software. *e*-M Plant^{TM} is an object-oriented simulation program that has the characteristics of hierarchy, inheritance, and concurrent simulation. Therefore, user-defined objects can be created, such as the OHT vehicle. Several user-defined objects are combined to form a new object, such as a track consisting of track, loadport, and OHT. The connecting transport AMHS is made up of machine, track, and stocker. The simulation models are developed using the unified modelling language (UML) in which the building procedures can be divided into four phases: inception, analysis, design and implement.

This study evaluates the performance of the number of vehicles in a dynamic connecting transport automated material handling system (AMHS) in a simplified 300 mm wafer fab. Using these simulation models, which closely match the logic that is implemented for the vehicle control system, allowed the authors to obtain the results while minimising time for model creation, verification, and validation. The model iterations were verified using flow charts. For each simulation run, several performance measures were collected after 48 hours of warm up time and stored in a data file for the validation. The results provide an approximate estimation of the performance of the proposed facility design. Then, the simulation model was used to analyse different scenarios that were obtained by altering the number of vehicles that were available for product movement. The simulation modelling assumptions are as follows.

1. Vehicles have a constant velocity of 60 m/minute and may have the accelerated speed ability.
2. It takes 20 seconds to move a lot from a vehicle.
3. The operation time of the crane in a stocker is a normally distributed ($\mu = 18$, $\sigma^2 = 5$) seconds.
4. The interarrival times of normal lots or hot lots at the source stockers are exponentially distributed (see table 3).
5. Hot lots always have priority over every normal lot during the movement period.
6. The lots are only transported between process tools, and not processed by the tool, to prevent any differences in process tool performance from affecting the transport vehicle. The number of buffers for each process tool is set at infinity for the same reason.
7. The simulation scope is limited to lot transportation and does not include the scheduling of production.

Table 3. The mean of the exponential distribution for the normal lots or hot lots.

Normal (100%)	70 lots/hr	140 lost/hr	210 lots/hr	Hot (0%)	70 lots/hr	140 lots/hr	210 lots/hr
E	3.622	1.811	1.207	ET	0.000	0.000	0.000
TF	5.176	2.588	1.725	TF	0.000	0.000	0.000
PH	9.578	4.789	3.193	PH	0.000	0.000	0.000
DF	14.800	7.400	4.933	DF	0.000	0.000	0.000
Normal (95%)	70 lots/hr	140 lost/hr	210 lots/hr	Hot (5%)	70 lots/hr	140 lots/hr	210 lots/hr
ET	3.441	1.720	1.147	ET	0.181	0.091	0.060
TF	4.917	2.458	1.639	TF	0.259	0.129	0.086
PH	9.099	4.549	3.033	PH	0.479	0.239	0.160
DF	14.060	7.030	4.687	DF	0.740	0.370	0.247
Normal (90%)	70 lots/hr	140 lost/hr	210 lots/hr	Hot (10%)	70 lots/hr	140 lots/hr	210 lots/hr
ET	3.260	1.630	1.087	ET	0.362	0.181	0.121
TF	4.658	2.329	1.553	TF	0.518	0.259	0.173
PH	8.620	4.310	2.873	PH	0.958	0.479	0.319
DF	13.320	6.660	4.440	DF	1.480	0.740	0.493

Note: ET = etching area; TF = thin-film area; PF = lithography area; DF = diffusion area.

The five major performance measures that are collected from the simulation are outlined as follows.

1. *Throughput:* The quantity of lots that complete transport in this system during the simulation time.
2. *Travel time:* Time is for a lot to travel from the output load port to the input load port of the destination tool. This includes the waiting time between the FOUP initiating a transportation task at the output load port of the source tool to placement on a vehicle.
3. *95% travel time:* Time is for 95% lots to finish the transport task.
4. *Waiting time:* Time is between the FOUP initiating a transportation task at the output load port of the source tool to placement on a vehicle.
5. *Empty vehicle utilisation* (%)*:* The percentage of available working time that a vehicle travel empty.

The flow rate and product-mix can affect the performance of the connecting transport AMHS. Thus, the flow rate can be 70 lots/hour, 140 lots/hour or 210 lots/hour. The ratio of normal lot to hot lot can be 100/0, 95/5 or 90/10. Thus, the factors are tested at 3×3 levels, which result in a 3×3 factorial design with nine experiments. In other words, each combination represents one operational scenario. With respect to the different flow rates, the upper limit and lower limit on the number of vehicles in each bay must be determined in advance for the simulation study. Using the approach in the previous section, the results are shown in table 4. Also, the total vehicle numbers for different flow rates (70 lots/hour, 140 lots/hour and 210 lots/hour) in the simulation model are 12, 23 and 34, respectively. A number of trial runs were performed to validate the model, and to determine a proper simulation warm-up period. First, it was observed that several statistics in the simulation started to show a smaller variation after about 48 hours. With this in mind, each simulation was run for 480 hours after

Table 4. The upper and lower limits on the number of vehicles in each intrabay.

	Upper limit (70 lots)	Upper limit (140 lots)	Upper limit (210 lots)	Lower limit
intrabay 1	2	4	7	1
intrabay 2	2	5	8	1
intrabay 3	3	6	9	1
intrabay 4	2	4	7	1
intrabay 5	2	5	7	1
intrabay 6	2	4	7	1
intrabay 7	2	2	2	1
intrabay 8	2	2	3	1

Table 5. The *P*-values of three main factors with interaction on the five performance measures.

Factor	Throughput	Travel time	95% travel time	Waiting time	Empty vehicle utilization
A	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*
B	0.4115	0.2430	0.0843	0.4853	0.2735
C	0.2972	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*
AB	0.2809	0.5799	0.0322*	0.9534	0.8778
AC	0.1916	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*
BC	0.6494	0.0452*	0.4684	0.7287	0.5504

Note: A = the flow rate; B = the ratio of normal lot to hot lot; C = strategy; * = significant at 95% confidence level.

a warm-up period of 48 hours. Each experiment was replicated five times. The total number of simulation experiments performed was 4 (strategies) × 9 (scenarios) × 5 (replications) = 180.

4. Analysis of simulation results

For each performance measure, the residual analysis showed that the assumptions (normality, constant variance for error term and independent) were satisfied, and further statistical analysis could be carried out. The *p*-values of the three main factors with interaction factors are shown in table 5. The results indicate that the flow rate significantly affects all five measures and the strategy significantly affects all five measures except the throughput at 95% confidence level. The ratio of the normal lot to hot lot does not significantly affect all five measures in this study. Also, some interaction factors significantly affect all five measures except the throughput. The least significant difference (LSD) method is used to compare all pairs of the four strategies under each of the nine scenarios. Results of the paired test analysis are summarized in table 4. The strategies are ranked with the English alphabet under each scenario for average throughput, travel time, 95% travel time, waiting time and empty vehicle utilization. Each value is the mean of the performance data that was collected in the five replications. An overall 95% confidence level is used in paired test analysis. With these four strategies, six pairwise comparisons can be conducted

Table 6. Summary results of the four strategies under different operational scenarios.

	Strategy	Throughput	Travel time	95% travel time	Waiting time	Empty-VU(%)
Scenario-1	S-1	29455(A)	365(D)	516(C)	52.9(B)	32.9(B)
70 lots/hr	S-2	29459(A)	216(B)	311(B)	22.5(A)	6.4(A)
hot lot = 0%	S-3	29520(A)	269(C)	340(B)	51.4(B)	31.8(B)
	S-4	29378(A)	132(A)	193(A)	21.9(A)	6.1(A)
Scenario-2	S-1	29441(A)	357(D)	475(D)	53.0(B)	33.0(B)
70 lots/hr	S-2	29432(A)	215(B)	247(B)	22.5(A)	6.4(A)
hot lot = 5%	S-3	29465(A)	291(C)	341(C)	51.2(B)	31.6(B)
	S-4	29523(A)	132(A)	194(A)	22.0(A)	6.1(A)
Scenario-3	S-1	29469(A)	365(D)	474(D)	53.1(B)	33.1(B)
70 lots/hr	S-2	29506(A)	217(B)	286(B)	22.5(A)	6.4(A)
hot lot = 10%	S-3	29370(A)	243(C)	332(C)	51.4(B)	31.8(B)
	S-4	29296(A)	132(A)	193(A)	21.9(A)	6.1(A)
Scenario-4	S-1	58872(A)	182(B)	277(C)	44.1(B)	24.1(B)
140 lots/hr	S-2	58712(A)	197(C)	203(B)	23.4(A)	6.4(A)
hot lot = 0%	S-3	59099(A)	163(B)	270(C)	44.0(B)	24.1(B)
	S-4	58889(A)	129(A)	193(A)	23.5(A)	6.5(A)
Scenario-5	S-1	58821(A)	188(C)	277(C)	44.0(B)	24.1(B)
140 lots/hr	S-2	58640(A)	197(C)	208(B)	23.4(A)	6.4(A)
hot lot = 5%	S-3	59125(A)	163(B)	270(C)	44.0(B)	24.1(B)
	S-4	58987(A)	129(A)	192(A)	23.5(A)	6.6(A)
Scenario-6	S-1	58970(A)	193(C)	277(B)	44.0(B)	24.1(B)
140 lots/hr	S-2	58971(A)	180(C)	198(A)	23.5(A)	6.5(A)
hot lot = 10%	S-3	58797(A)	163(B)	270(B)	43.9(B)	24.1(B)
	S-4	59066(A)	129(A)	192(A)	23.6(A)	6.6(A)
Scenario-7	S-1	88534(A)	167(C)	279(D)	40.7(C)	19.7(C)
210 lots/hr	S-2	88492(A)	195(D)	233(B)	27.4(A)	8.1(A)
hot lot = 0%	S-3	88316(A)	150(B)	249(C)	33.9(B)	13.9(B)
	S-4	88370(A)	141(A)	227(A)	27.4(A)	8.1(A)
Scenario-8	S-1	88443(A)	172(C)	279(B)	40.6(B)	19.7(B)
210 lots/hr	S-2	88133(A)	183(C)	233(A)	27.3(A)	8.0(A)
hot lot = 5%	S-3	88125(A)	159(B)	272(B)	40.4(B)	19.6(B)
	S-4	88256(A)	141(A)	227(A)	27.4(A)	8.1(A)
Scenario-9	S-1	88506(A)	175(C)	279(B)	40.7(B)	19.7(B)
210 lots/hr	S-2	88268(A)	182(C)	233(A)	27.4(A)	8.0(A)
hot lot = 10%	S-3	88527(A)	159(B)	271(B)	40.6(B)	19.8(B)
	S-4	88235(A)	141(A)	227(A)	27.4(A)	8.1(A)

Note: Strategies with the same English alphabet (A, B, C, D) represent they are not significantly different at 95% confidence level.

under each scenario for each performance measure. The information that is contained in table 5 can provide guidance for decision makers in the selection of preferable strategies, based on the different operation environment and performance measures. Ranking comparisons for all four strategies based on table 6 show that the strategy 4 outperformed the others for all performance measures except the average throughput. With respect to the average throughput, no strategies outperformed the others. With respect to the average waiting time and empty vehicle utilization, both strategy 2 and strategy 4 have the same performance. The results indicate that the control with the lower limit of the vehicle numbers significantly affects the travel time, the 95% travel time, the waiting time and the empty vehicle utilisation.

5. Conclusions

A performance evaluation of the dynamic connecting transport of an automated material handling system (AMHS) in a simplified 300 mm wafer fab was conducted by considering the effects of the number of vehicles. In order to avoid congestion or idle time in the intrabay system, the control of the upper limit or the lower limit on the number of vehicles can be the feasible solution. Using *e*-M Plant^{TM} simulation models, the capabilities of these four strategies were demonstrated. The following conclusions can be made.

- The flow rate and the strategy significantly affect all performance measures at 95% confidence level in this simulation study.
- The results show that the strategy 4 outperforms the others for all performance measures except the average throughput. With respect to the average throughput, no strategies outperformed the others. That is, the best strategy for each intrabay is with the upper and lower limits of the vehicle numbers.
- The results indicate that the control with the lower limit on the number of vehicles significantly affects the travel time, the 95% travel time, the waiting time and the empty vehicle utilization.

Future research could focus on the integration of the lot transportation and lot scheduling. Moreover, the effect of dispatch rules on the dynamic connecting transport merits further study.

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