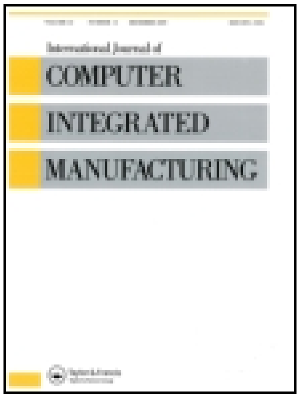

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The transport strategies for fully automated manufacturing in 300 mm wafer fab

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The transport strategies for fully automated manufacturing in 300 mm wafer fab

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This paper addresses the operational issues of transport strategies in tool and vehicle dispatching integration (TVDI) architecture in a fully automated manufacturing wafer fab. At present, there are three transport strategies involved in vehicle dispatching, namely, *avoid blocking, avoid starvation*, and *accelerate batch preparation*. These strategies were developed to obviate production obstacles and to avoid capacity loss. Consequently, there are five levels in the decision-making process of TVDI, namely, *dispatching request, conditions checking, candidate selection, dispatching rules*, and *result execution*. Specifically, *candidate selection* was classified into five categories: FOUP-selects-tool (FST), FOUP-selects-stocker (FSS), tool-selects-FOUP (TSF), FOUP-selects-vehicle (FSV), and vehicle-selects-FOUP (VSF). The proposed transport strategies were implemented in VSF, and a simulation model abstracted from a wafer fab in Taiwan was used to evaluate the performance. The results show that the differences in the proposed strategies compared with ignoring the issues are statistically significant, and the performances of the wafer output, cycle time and waiting time can be improved.

Keywords: dispatching; integration; transport; AMHS; wafer fab; simulation

1. Introduction

Since increasing the technology of integrated circuit (IC) manufacturing from 0.18 μm to 0.13 μm, or even smaller than 0.1 μm, airborne molecular contaminants (AMC) in the clean room had negative effects during the process, which eventually affected the yield. For this reason, mini-environment (Brain and Abuzeid 1994) manufacturing, which emphasises maintenance of the cleanliness classification, is implemented. Aside from its economic benefits, the size of the wafer also increases from 200 mm to 300 mm. Also, the fully automated transport is implanted because of its ergonomic requirement. Fully automated manufacturing is consequently introduced in the 300 mm wafer fab. It brings the greatest challenge of integrating the transport and the production elements, particularly at the operational level, tool dispatching (TD) and vehicle dispatching (VD). Moreover, an automated material handling system (AMHS) for delivering the heavy 300 mm wafers without human involvement is the result of a breakthrough in the transport system (Kaempf 1997, Kurosaki *et al*. 1997, Bahri *et al*. 2001).

Generally, the 300 mm AMHS is implemented as many separate loops, spreading out from a central loop, and is connected in front of each functional process bay. Both loops are located overhead to attain zero footprints in transport and to minimise the fab footprint (see Figure 1). The wafer carrier, or the front-opening unified pod (FOUP), is a kind of closed carrier with an automated door at the front side. On the other hand, the vehicle, an overhead hoist transporter (OHT), is capable of carrying one FOUP at a time and has a hoisting mechanism that automatically loads and unloads one FOUP. Under this transport configuration, vehicles are not restricted to one designated loop, but are allowed to travel all around the wide fab. At the same time, the FOUP can be delivered directly through stockers or tool-to-tool to their destination. Hence, a matrix of transport capabilities can also be provided (Plata 1997).

The dispatching is triggered by the production or transport request. The *production request* is that FOUP has to be *pushed* to the downstream tool when it has already been accomplished as a process step, or the tool *pulls* the FOUP for the next task when its capacity is released. Furthermore, the *transport request* is initialled by the production request for transporting the FOUP (either *pushed* or *pulled*) to the designated location. However, these requests might not be executed immediately owing to the limited resources. Thus, the dispatching is raised to check the available capability and to determine the resource allocation based on the designated rule.

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Moreover, TD involves the determination of which FOUP should be process first, given that many FOUPs are waiting to be processed. Tyan *et al.* (2002) used theory of constraint (TOC) principles to propose the state-dependent dispatching rule that is especially designed for the bottleneck station. Meanwhile, Dabbas and Fowler (2003) classified the rules as local or global policies. The global policies include the look-behind and look-ahead strategies, which make a timely decision within and outside its immediate neighbourhood because of their re-entrance characteristics. In addition, some issues are focused on particular restrictions, such as mask scheduling, tool dedication, and full-batch. The mask scheduling attempts to minimise the mask change times to reduce set-up time. For example, family-based rules, which group the same photo mask as a family, were proposed by Chern and Liu (2003) to balance the workload between two consecutive exposure operations. These rules were said to be similar to the workload-levelling algorithm proposed by Kim *et al.* (1998). Tool dedication, which aims to balance the workload of the selected tool, is like the evaluation of the flexible assignment policy and dedicated assignment policy by Akcalt *et al.* (2001), and the line balance algorithm by Wu *et al.* (2006), which also aims to smooth the flow rate between multiple photo layers. Furthermore, the full-batch process combines multiple lots with the same recipe for cleaning or oxidation deposition, and the related issue is intended to reduce the production variance owing to the batch collection. Weng and Leachman (1993) used the information about future arrival to develop the minimum cost rate heuristic for reducing the variation in lead times. Also, Kim *et al.* (1998) proposed the back and front queues levelling rule to avoid starvation of the workstation. In fact, the idea of a kanban card or the pull approach used in the time constraint between wet etch and furnace was introduced by Scholl and Domaschke (2000).

VD involves the determination of which FOUP to transport first, given that many FOUPs are waiting to be moved. The related topic has appeared earlier in an automatic guide vehicle (AGV) system, and similar issues are extended to the AMHS in fab. Egbelu and Tanchoco (1984) classified the AGV dispatching into two categories specifically the work centre-initiated and the vehicle-initiated. The work centre-initiated approach involves the work centre requesting a vehicle, from a set of available vehicles, to move out a load in its output queue. On the other hand, the vehicle-initiated dispatching approach involves the vehicle asking for the next load, from a set of loads which are waiting to be moved. Egbelu (1987) further classified the vehicle-initiated dispatching approach as source-driven and demand-driven. The decision criterion of source-driven dispatching approach is focused on the conditions of the work centre where the loads originate, while the work centre conditions of the destination are considered the essential criterion in the demand-driven dispatching approach. A new classification of dispatching systems presented by Le-Anh and de Koster (2006) were decentralised and centralised, and the general objectives of dispatching included minimising waiting time, maximising throughput, minimising queue length, and guaranteeing a certain service level were introduced.

For the AMHS in fab, Lin *et al.* (2001) outlined the dispatching system in a double loop interbay with the three decision points, namely, the loop selection, cassette-initiated rule, and vehicle-initiated rule. Meanwhile, Wang and Liao (2003, 2004) developed the policies, which are classified as preemptive highest priority job first (PHP) and differentiated preemptive dispatching (DPD) to enhance the service of hot lot by reducing the frequent blockage of the normal lots transport. Lin *et al.* (2006) introduced a hybrid push-pull rule for a photobay, and the numbers of input/retrieve in the stocker can be decreased. In the connecting AMHS, Lin *et al.* (2003a) classified the vehicle into four types to service the designated area; tool-to-tool delivery can then be accomplished with the combination of the different vehicle types. Furthermore, the mixture of the different combination of vehicle types was presented by Lin *et al.* (2003b) and the optimum mixture percentage could be obtained through the application of the response surface methodology. Vehicle types can also be changed for various task requests according to Lin *et al.* (2004) to make the dispatch more flexible. Conversely, the multi-attribute metric of vehicle reassignment was proposed by Kim *et al.* (2007), and the empty trip distance as well as the waiting time of the load would be taken into account in determining the delivery task. Sha *et al.* (2008) addressed the search range assignment for dispatching, indirectly to limit the distance of a vehicle's empty trip which will eventually make the vehicle work effectively.

In the literature, much effort has been put into enhancing the performance of TD or VD separately. However, the dynamic of traffic has been ignored in TD studies. Also, tool status like blocking or starvation has not been considered in VD studies, or has been set as a constant time delay. Researchers believe that these two issues should be discussed simultaneously in fully automated manufacturing owing to the close interactions between production and transport. In addition, most VDs in the existing literature are based on the status of the tasks or tools where the *tasks originate*. This type of dispatching is inflexible in a fully automated wafer fab, as shown in section 2. Therefore, this study

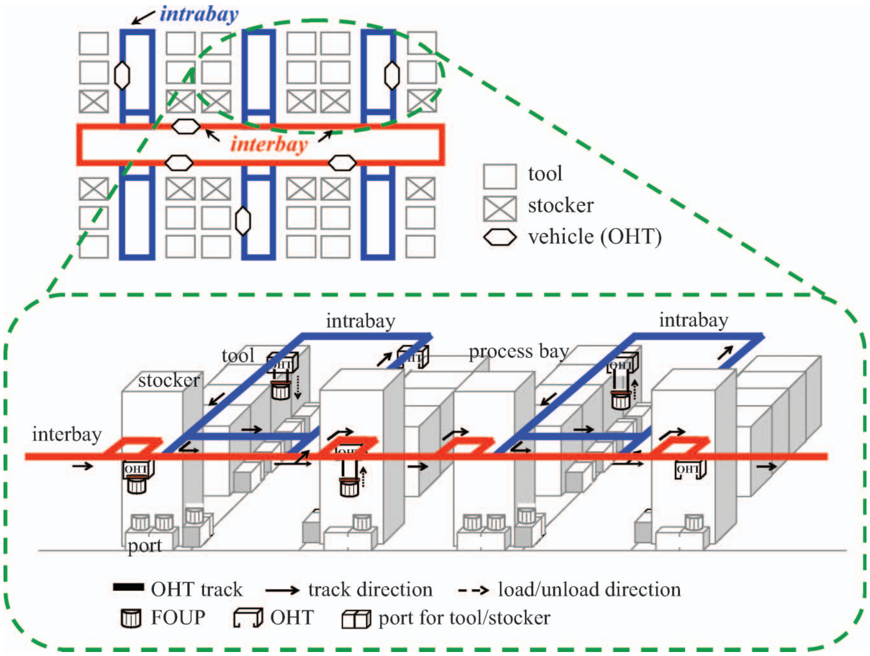

Figure 1. Configuration of a 300 mm wafer fab.

attempts to propose strategies in VD (named *transport strategy*) which will determine the task's transport priority based on the status of the tool, either the *tasks originate* or the *task's destination*, in tool and vehicle dispatching integration (TVDI) architecture. Likewise, the performance was evaluated using a simulation built in the object-oriented software eM-Plant™.

The study is presented in the following sections. Specifically, the problem statement is addressed in section 2 while the three transport strategies are presented in section 3. Also, the interactions between TD and VD are presented in section 4 and the simulation experiment is reported on section 5. Lastly, conclusions are presented in the final section, along with suggestions for further research.

2. Problem statement

The dispatching procedure of the object fab shown in Figure 2 illustrates that the transport priority of the FOUP (defined as a process unit with 25 pieces of wafer in it) is based on *the longest waiting time first*, as the source-driven dispatching. It might appear that a FOUP is being moved to a tool, but in reality, many FOUPs are ready for process in the tool's port, which means that the tool does not need more work in progress (WIP). The same circumstance occurs if the FOUP is transported to its downstream tool, however, this FOUP keeps circulating on the vehicle because the tool is blocked and there are no available ports to load it on. At the same time, other starving tools remain idle, and the tool's capacity might be lost because the FOUP requested by the starving tools is waiting for transport – this FOUP is not *the longest waiting*. Also, FOUP might not obtain the highest priority (*the longest waiting time*) to be moved for gathering in the stocker before the furnace process. This means that there will be a larger variance time period for batch collection. Unfortunately, these situations are caused by omitting a tool's capability when executing VD and the vehicles transporting the *wrong* FOUP to the *wrong* tool. This also implies that there is a misallocation of vehicles.

Thus, it is necessary to identify the interactions between TD and VD, and to develop a transport strategy that will adjust the FOUP's transport priority according to 'special properties' for better vehicle allocation.

3. Transport strategies

The demand-driven transport strategies, considering the tool states like blocking, starvation, and batch processing, are proposed. Hence, the functions of transport are not only to provide service to the *production request* as described in section 1, but also to carry out some *activities* that will make the production more efficient like obviating production obstacles or avoiding capacity loss.

3.1. Avoid blocking

To avoid tool blocking, there is a need to detect the states of a tool's port. This will determine if there is

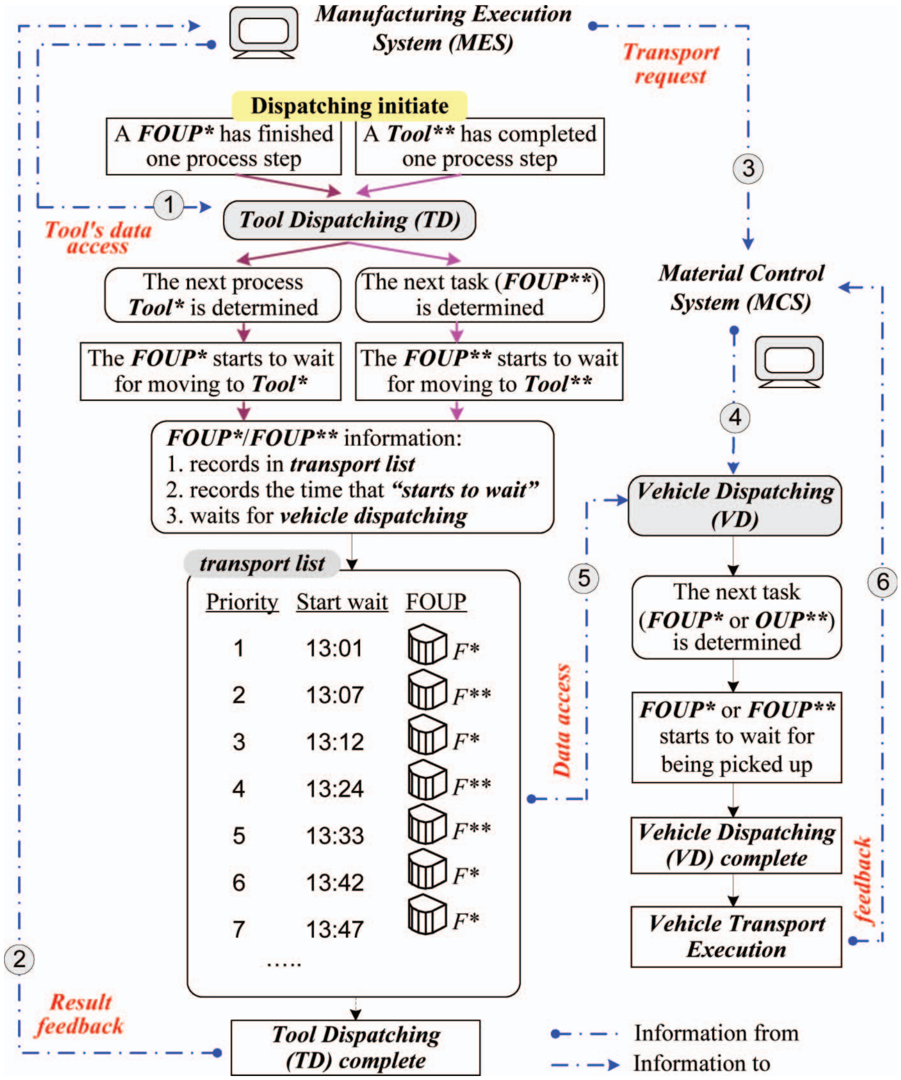

Figure 2. Dispatching decision-making procedure.

tool blocking occurrence. Specifically, there are five states of a tool's port identified in the study. They are notated as *Pa*, *Pr*, *Pp*, *Pn*, and *Po*.

(1) *Pa*: port available for assignment (avail.-port).
(2) Occupied port:
  (a) *Pr*: the port is reserved by a FOUP on the way to this tool (res.-port).
  (b) *Pp*: the port is occupied by a FOUP which the wafers in it are processing now (proc.-port)
  (c) *Pn*: the port is occupied by a FOUP which is waiting for processing (in-port).
  (d) *Po*: the port is occupied by a FOUP which is waiting to be moved (out-port).

The state of the port changes dynamically and is in only one, of the five states. *nPa, nPr, nPp, nPn*, and *nPo* are the ports numbered *Pa, Pr, Pp, Pn*, and *Po* of a tool respectively. To determine the number of available ports, the equation is $nPa = nP - nPr - nPp - nPn - nPo$, where nP is the total number of a tool's port and $nPa \in \{0,1, \ldots, nP\}$, $nPr \in \{0,1, \ldots, nP\}$, $nPp \in \{0,1\}$, $nPn \in \{0,1, \ldots, nP\text{-}1\}$, $nPo \in \{0,1, \ldots, nP\}$. Likewise, *blocking* occurs if $nPa = 0$, $nPo > 0$, and if there is a FOUP scheduled to be loaded to this tool. The FOUP in *Po* is considered as a *blocking FOUP*.

For example, tool A has four ports in Figure 3, and FOUPs f_5 and f_6 are scheduled for loading to the tool but are stored somewhere. Meanwhile, f_2 is processed and f_1 is scheduled for processing after f_2. f_3 have finished the step and f_4 is being moved to port *c* by v_1. The states of ports *a, b, c*, and *d* at this time are *Pn, Pp, Pr*, and *Po* respectively. *nPn, nPp, nPr*, and *nPo* are the same, and have no available port. In this case, *blocking*

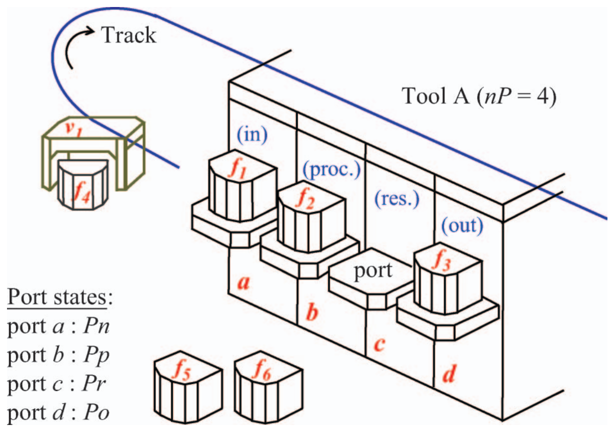

Figure 3. States of a tool's port.

occurs because $nPa = 0$, $nPo = 1 > 0$, f_5 and f_6 are queued to be processed. The f_3 is a *blocking FOUP*, and f_5 or f_6 cannot be loaded in the tool until f_3 is moved out.

The *avoid blocking* strategy will enable a higher priority of *blocking FOUP* to be transported, which leads to the release of the port's capacity. Furthermore, the tool's blocking status is removed and the production obstacle is obviated.

3.2. Avoid starvation

The *avoid starvation* strategy will enable a higher transport priority to the FOUP (named *starved FOUP*), which is requested by the *most starving tool group*, the tool group which has the Max (UD_i). The following notations are used to illustrate:

(1) i: tool group where $i = 1, 2, \ldots, n$. n: number of tool groups.
(2) j: tool, where $j = 1, 2, \ldots, n_i$. n_i: number of tools which belong to i, $j \in i$.
(3) UP_i: planned utilisation of i, which is calculated using the static capacity analysis under the planned wafer out per month.
(4) $UA_{i,j}$: average actual utilisation of j, $j \in i$.
(5) UA_i: average actual utilisation of i, where $UA_i = \sum_{j=1}^{n_i} UA_{i,j}/n_i$, $j \in i$.
(6) UD_i: average difference utilisation, where $UD_i = UP_i - UA_i$.

The $UA_{i,j}$, UA_i, and UD_i are calculated every 12 hours (2 shifts/day). This strategy indicates that in order to reach the planned wafer out, the UA_i has to achieve the planned UP_i. This also implies that the tool's move (the volume of process complete) does not meet the plan, in fact, the tool is idle more than the expected time, making many FOUPs pile up somewhere. Thus, if a tool group has the highest UD_i, it is considered as the *most starving tool group* in the pipeline. Hence, the *starved FOUP* is given a higher priority using the *avoid starvation* strategy, which will in turn avoid the capacity loss and smooth out the production.

3.3. Accelerate batch preparation

Moreover, the production cycle of the FOUP consists of three elements, namely, processing, transporting, and waiting, where waiting time is adjustible to reductions depending on dispatching decisions. Owing to the need to fill a batch of up to six FOUPs in the stocker before the furnace process, the waiting time for the batch preparation is considered a key element in increasing the cycle time. Figure 4 shows the time for the FOUP to prepare the batch process. It explains the shortened length of time for period 1 and period 3, i.e. the time the FOUP waits for VD in the tool's out-port, the waiting time can be reduced and batch preparation can be accelerated.

Likewise, the *accelerate batch preparation* strategy will enable a higher priority of FOUP (named *batch FOUP*), which fulfills the status in both time periods 1 and 3 to be transported. Then, not only can the variance time period to prepare the batch be decreased, but also the capacity loss owing to the tool being idle for batch preparation can be reduced.

4. Dispatching interactions

4.1. Decision-making procedures

A five-level decision-making procedure is implemented in the TVDI architecture. The first level is the *dispatching request*, in which the request is triggered by a production or transport event: (e1) when a FOUP has just finished one process; (e2) when a FOUP is picked up from the tool's port by a vehicle and the capacity of the tool's port has just been released; (e3) when FOUPs required to form a batch are available in the stocker; (e4) when a movement request from FOUP is initiated by above three events; (e5) when a vehicle unloads a FOUP at a tool's port, and the vehicle's capacity has just been released. The events (e1), (e2) and (e3) are for production and (e4) and (e5) are for transport.

The second level is the *resource checking*, in which the status and capability of the resources, either tools or vehicles, will be assessed in order to determine whether the FOUP is to be transported to the next process, to be stored in the stocker, or to be kept waiting in the tool's port. Once the resource is checked, the third level, which is the *candidate selection*, is executed. For instance, if a vehicle is determined to transport one FOUP through *resource checking*, then

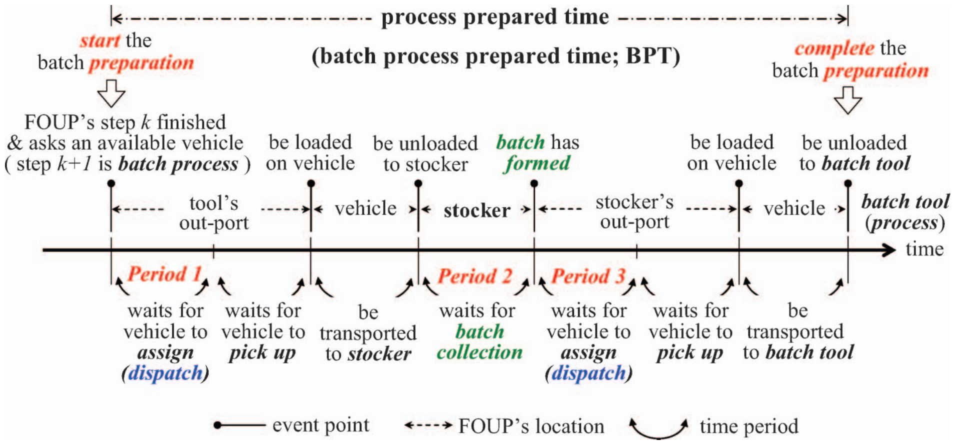

Figure 4. Time composing of batch process preparation.

FOUPs which have 'special property' will be selected as candidates for transport in this level.

Accordingly, the authors further classified the *candidate selection* into five categories, as the FOUP-selects-tool (FST), the FOUP-selects-stocker (FSS), the tool-selects-FOUP (TSF), the FOUP-selects-vehicle (FSV), and the vehicle-selects-FOUP (VSF). FST, FSS, and TSF belong to TD, while FSV and VSF are parts of VD.

(1) FST deals with the selection of a specific tool from a set of available tools to process a FOUP's next step.
(2) FSS deals with the selection of a stocker for temporarily storage due to FOUP's next step tool which is blocking, or the selection of an appropriate stocker for batch collection.
(3) TSF deals with the selection of a specific FOUP from a set of waiting FOUP as a tool's next task.
(4) FSV deals with the selection of a vehicle from a set of available vehicles to transport a FOUP which requests to move.
(5) VSF deals with the selection of a FOUP from a set of waiting FOUP as a vehicle's next delivery task when the vehicle just completed a task.

The VSF operation is the focal point in this study. The *blocking FOUP, starved FOUP*, and *batch FOUP*, which have 'special properties' will be selected as candidates first. This means that they have the higher transport priority.

The fourth level is the *dispatching rules*, in which a tool or a vehicle determines the next task from the candidate, or a FOUP requests a tool or vehicle from the candidate based on the defined rules. The candidate on this level is obtained from the previous level. Finally, the fifth level is the *result execution*, in which the transport, production or storage will be executed after the four previous levels have been accomplished.

The detailed interactions between TD and VD are elaborated in Figure 5, and in which the third and fourth levels are listed in Table 1.

4.2. Interactions remarks

Some dispatching interactions remarks are as follows:

(1) (e1) and (e3) are the events that *push* the FOUP into the next process, while (e2) implies that a tool asks to *pull* the next task and (e5) indicates that a vehicle requests the next task.
(2) FSV is triggered after a series of production events (e1), (e2) or (e3) that request to transport the specific FOUP to the assigned location.
(3) The *blocking* status of the current and downstream tool will be detected when (e1) occurs.
(4) The *available batch* in (e2) means FOUPs have formed the batch in the stocker and are ready for a tool to call for processing (TSF).
(5) The interactions between the *candidate selection*:
    (5.1) a* following (e1) and c* following (e3) indicate that a FOUP has failed to be *pushed* to the next process (FST), and waits for a downstream tool to trigger TSF to *pull* (waits (e2) occurs).
    (5.2) b* following (e2) indicates that a tool has failed to *pull* the next task (TSF), and waits for FOUPs to trigger FST to assign (waits (e1) occurs).
    (5.3) d* following (e4) from (e1), (e2) and (e3) indicates that a FOUP has failed to call for a vehicle (FSV) and is waiting for a vehicle to trigger VSF to assign (waits (e5) occurs).

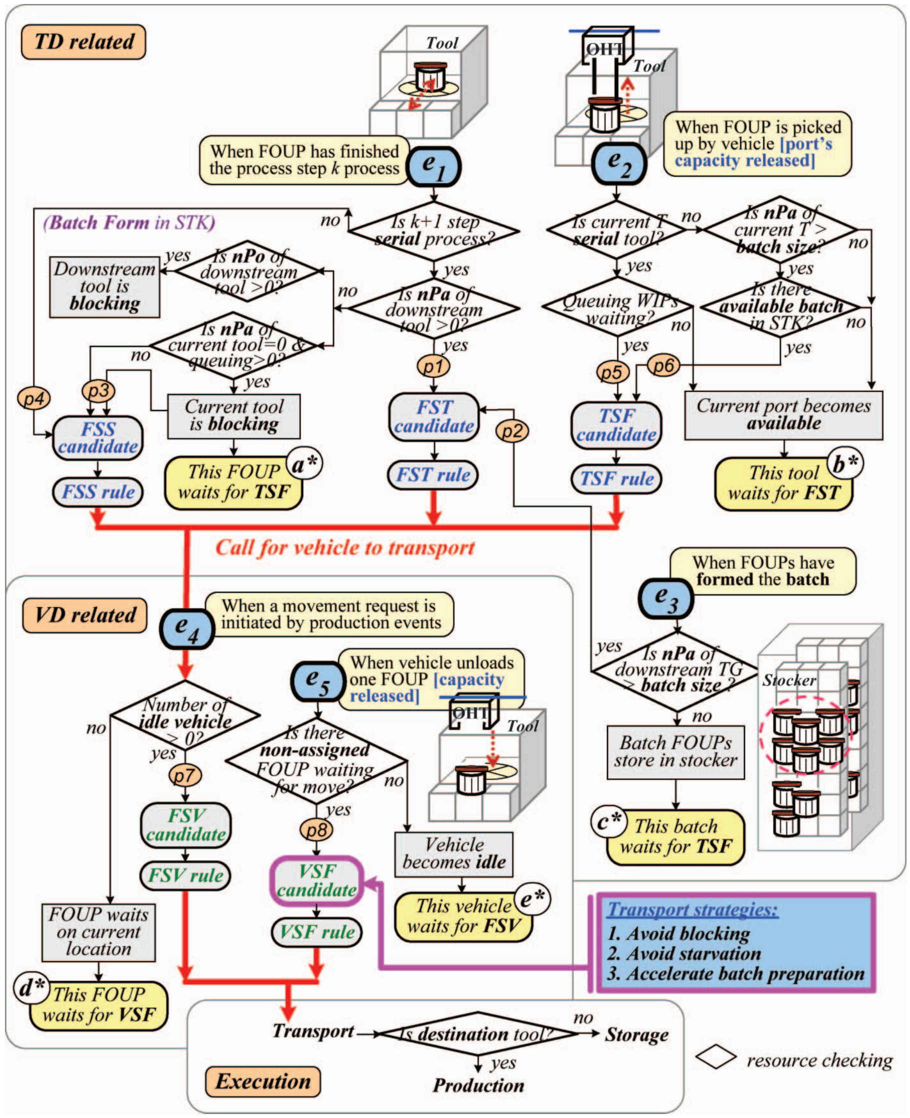

Figure 5. Representation of dispatching interactions.

(5.4) *e** following (e5) indicates that a vehicle has failed to request the next task (VSF), and is idle until a FOUP triggers FSV to assign (waits (e4) occurs).

(6) *Avoid blocking* promotes the release of a port's capacity while *avoid starvation* enables the starving tool to be fed as soon as possible.

(7) *Accelerate batch preparation* attempts to reduce the time required by FOUPs to collect the batch in the stocker, and then shortening the time period to (e3) occurs.

5. Simulation experiment

5.1. *Capacity facilitated*

The allocation of a production area and the track design of the material handling of a real fab in Taiwan are abstracted in Figure 6. The capacity plan is based on static capacity analysis with one process flow, 0.13μm logic IC. The capacity plan also assumes that there are 6,000 pieces of wafer output per month, and keeps the tool utilisation below 90%. Accordingly, the 736 steps (without manual inspection) with 33 photo layers requires a net time of 352.41 h (approximately 14.7 days) to process (For the process flow information, please see Appendix 1). The 72 tool groups and 141 tools required for the above processing are facilitated and listed in Table 2.

The AMHS includes one interbay and ten intrabays, and the types of track such as intrabay U-turn track, shortcut and bypass are facilitated. The U-turn track is located within the bay handling, while the shortcut track is located for a short transport distance. The bypass is installed for a vehicle to travel straight

Table 1. *Candidate selection* and *dispatching rules* in decision-making process.

FST	***Candidate selection***				
	p1	Identify the *candidate tool set* from all downstream tool j where tool's $nPa > 0$			
	p2	Identify the *candidate tool set* from all downstream tool j where tool's $nPa >=$ batch size			
	Rule: the lowest utilization first (LU)				
FSS	***Candidate selection***				
	p3	Identify the *candidate STK set* Y from all STKs which correspond to tool group i			
	p4	Identify the set Y from all STKs which correspond to tool group i Identify the set $y \in Y$ where exists non-available batch (incomplete batch) If $y \neq Ø$, *candidate STK set* is y. Else ($y = Ø$), *candidate STK set* is Y			
	Rule: the lowest WIP level first (LWL)				
TSF	***Candidate selection***				
	p5	Identify the *candidate FOUP set* from all FOUPs which are non-assigned to tool			
	p6	Identify the *candidate FOUPs set* from all FOUPs which are available batch and non-assigned to tool			
	Rule: the first come first service (FCFS)				
FSV	***Candidate selection***				
	p7	Identify the *candidate vehicle set* from all vehicles which are idle			
	Rule: the nearest vehicle first (NV)				
VSF	***Candidate selection***				
	p8	Identify the following sets: (1) set W from FOUPs which are non-assigned to vehicle and queuing for transport; (2) set $b \in W$ from FOUPs which are *blocking FOUP* (3) set $s \in W$ from FOUPs which are *starvation FOUP* (4) set $f \in W$ from FOUPs which are *batch FOUP* (5) set $x_1 = \{FOUP \mid (b \cap s)\}$, set $x_2 = \{FOUP \mid (b \cap f)\}$, set $x_3 = \{FOUP \mid (s \cap f)\}$, set $x_4 = \{FOUP \mid (b \cup s)\}$, set $x_5 = \{FOUP \mid (b \cup f)\}$, set $x_6 = \{FOUP \mid (s \cup f)\}$, set $x_7 = \{FOUP \mid (b \cap s \cap f)\}$, set $x_8 = \{FOUP \mid b \cup s \cup f)\}$ set $x_9 = \{FOUP \mid (b \cap s) \cup (b \cap f) \cup (s \cap f)\}$ Then the *candidate FOUP set* is identified under different scenarios (see Section 5.5).			
		➢ **Scenario 1: $A_1B_1C_1$**			
		$b = Ø$	$s = Ø$	$f = Ø$	*set W*
				$f \neq Ø$	*set f*
			$s \neq Ø$	$f = Ø$	*set s*
				$f \neq Ø$	If $x_3 \neq Ø$, *set* x_3. Else ($x_3 = Ø$), *set* x_6
		$b \neq Ø$	$s = Ø$	$f = Ø$	*set b*
				$f \neq Ø$	If $x_2 \neq Ø$, *set* x_2. Else ($x_2 = Ø$), *set* x_5
			$s \neq Ø$	$f = Ø$	If $x_1 \neq Ø$, *set* x_1. Else ($x_1 = Ø$), *set* x_4
				$f \neq Ø$	If $x_7 \neq Ø$, *set* x_7. Else if $x_1 \neq Ø$ or $x_2 \neq Ø$ or $x_3 \neq Ø$, *set* x_9. Else ($x_7 = Ø$ & $x_9 = Ø$), *set* x_8.
		➢ **Scenario 2: $A_1B_1C_2$**			
		$b = Ø$	$s = Ø$		*set W*
			$s \neq Ø$		*set s*
		$b \neq Ø$	$s = Ø$		*set b*
			$s \neq Ø$		If $x_1 \neq Ø$, *set* x_1. Else ($x_1 = Ø$), *set* x_4
		➢ **Scenario 3: $A_1B_2C_1$**			
		$b = Ø$		$f = Ø$	*set W*
				$f \neq Ø$	*set f*
		$b \neq Ø$		$f = Ø$	*set b*
				$f \neq Ø$	If $x_2 \neq Ø$, *set* x_2. Else ($x_2 = Ø$), *set* x_5
		➢ **Scenario 4: $A_1B_2C_2$**			
		$b = Ø$			*set W*
		$b \neq Ø$			*set b*
		➢ **Scenario 5: $A_2B_1C_1$**			
			$s = Ø$	$f = Ø$	*set W*
				$f \neq Ø$	*set f*
			$s \neq Ø$	$f = Ø$	*set s*
				$f \neq Ø$	If $x_3 \neq Ø$, *set* x_3. Else ($x_3 = Ø$), *set* x_6
		➢ **Scenario 6: $A_2B_1C_2$**			
			$s = Ø$		*set W*
			$s \neq Ø$		*set s*
		➢ **Scenario 7: $A_2B_2C_1$**			
				$f = Ø$	*set W*
				$f \neq Ø$	*set f*
		➢ **Scenario 8: $A_2B_2C_2$**			
					set W
	Rule: the longest waiting time first (LWT)				

p1 ~ p8: path marks from Figure 5.

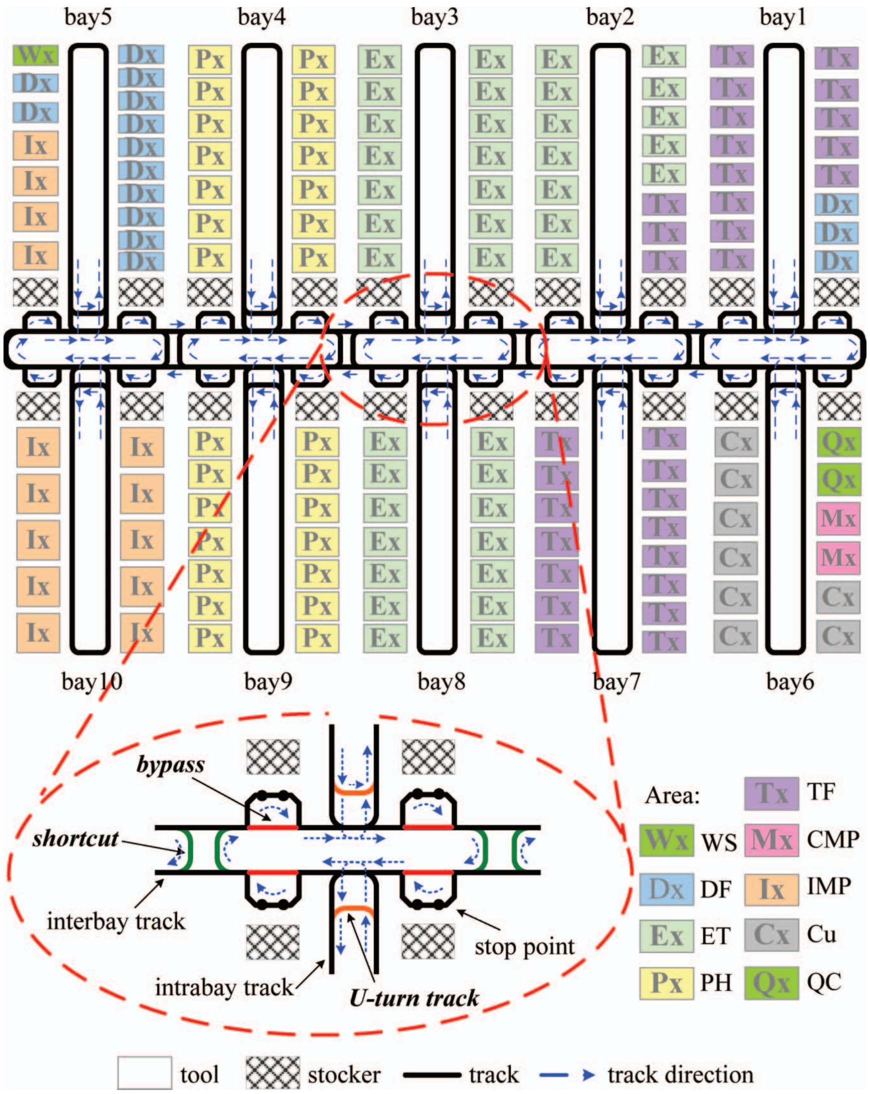

Figure 6. Representative layout of a 300 mm wafer fab.

Table 2. Capacity facilitated.

Production Area	TG number			Tool number			Critical TG	
	Prod.	Insp.	No.	Prod.	Insp.	No.	No.	Util.%
WS	1	0	1	1	0	1	0	
TF	15	1	16	30	1	31	1	84.01
ET	14	5	19	34	6	40	5	83.98
DF	9	2	11	13	2	15	1	82.12
PH	6	6	12	15	13	28	2	84.46
IMP	5	0	5	14	0	14	2	86.86
CMP	2	0	2	2	0	2	0	
CU	2	2	4	6	2	8	0	
QC	0	2	2	0	2	2	0	
Total	54	18	**72**	115	26	**141**	**11**	84.29

TG: tool group; Prod.: production tools; Insp.: Inspection tools.

forward without the obstruction of another vehicle in front, which is assumed to be loading/unloading with a stocker. Thus, a vehicle travels and turns to the direction of the stocker's stopping point if it needs to input/retrieve a FOUP from the stocker. This track reduces traffic congestion, which might be caused by the delay of executing the loading/unloading process along the traffic arteries (interbay).

5.2. System behaviour

The following system behaviour is described: (1) only one product described above has been implemented due to process flow confidentiality; (2) the uniform loading (UL) (Glassey and Resende 1988) open-loop wafer release policy was adopted (200 pieces/day); (3) batch size of the furnace processing is six units, and the FOUP has to form the batch in stocker; (4) furnace tools are embedded with internal storage (twelve units) for batching; (5) four ports of furnace and photo tools, and three ports for other tools; (6) the direction of a port is bi-directional; (7) FOUP's movement request from tool is sequential. That is, the next movement request from a tool can be initiated only when the present FOUP is moved out; (8) the traveling path is based on the shortest distance; (9) the zone control (Garry 1987) is used to prevent traffic collision.

5.3. Model assumptions

The following assumptions are made: (1) process times are constant, with no set-up time, no reworking and no yield loss; (2) breakdown of tool and stocker are not considered; (3) acceleration and deceleration of the vehicle are ignored; (4) breakdown and battery recharge of the vehicle are not considered.

5.4. Performance indices

The performance indices are: (1) wafer out (WO, pieces/month) – an average number of wafers output per month; (2) cycle time (CT, hrs) – the average time for the wafers to enter and then leave the system; (3) batch process prepared time (BPT, hrs) – the average time for wafers to prepare batch process. That is, the time from 'start' to 'complete'

Table 3. AVOVA for the transport strategies experiment.

Source	Sum of squares	DF	Mean square	F-value	Prob > F	
(1) Response: TP						
Model	96764.3	7	13823.5	46.2	< 0.0001*	significant
A	4069.0	1	4069.0	13.6	0.0020*	
B	1881.5	1	1881.5	6.3	0.0234*	
C	2350.3	1	2350.3	7.8	0.0128*	
AB	49277.3	1	49277.3	164.5	< 0.0001*	
AC	1100.3	1	1100.3	3.7	0.0733	
BC	16933.6	1	16933.6	56.5	< 0.0001*	
ABC	21152.3	1	21152.3	70.6	< 0.0001*	
Pure error	4791.7	16	299.5	R-squared:0.9528		
Cor total	101556.0	23		Adj R-squared:0.9322		
(2) Response: CT						
Model	1534.1	7	219.2	41.6	< 0.0001*	significant
A	218.9	1	218.9	41.5	< 0.0001*	
B	28.1	1	28.1	5.3	0.0347*	
C	227.8	1	227.8	43.2	< 0.0001*	
AB	444.4	1	444.4	84.3	< 0.0001*	
AC	393.1	1	393.1	74.6	< 0.0001*	
BC	32.1	1	32.1	6.1	0.0252*	
ABC	189.6	1	189.6	36.0	< 0.0001*	
Pure error	84.3	16	5.3	R-squared:0.9479		
Cor total	1618.4	23		Adj R-squared:0.9251		
(3) Response: BPT						
Model	3211.1	7	458.7	8128.8	< 0.0001*	significant
A	1283.0	1	1283.0	22734.8	< 0.0001*	
B	469.2	1	469.2	8314.0	< 0.0001*	
C	716.0	1	716.0	12687.1	< 0.0001*	
AB	362.3	1	362.3	6420.2	< 0.0001*	
AC	245.9	1	245.9	4358.2	< 0.0001*	
BC	69.7	1	69.7	1234.8	< 0.0001*	
ABC	65.0	1	65.0	1152.4	< 0.0001*	
Pure error	0.9	16	0.1	R-Squared:0.9997		
Cor total	3212.0	23		Adj R-Squared:0.9996		

*significant at 95% confidence level.

the batch preparation in Figure 4. A total of 19 steps BPT among process flow (736 steps) will be summarised.

5.5. *Design of experiment*

Three strategies implemented during the *candidate selection*, VSF, were evaluated. The factors and levels were as follows:

(1) Factor A: blocking; two levels. Levels are A_1 = *avoid blocking*, A_2 = ignore blocking.
(2) Factor B: starvation; two levels. Levels are B_1 = *avoid starvation*, B_2 = ignore starvation.
(3) Factor C: batch preparation; two levels. Levels are C_1 = *accelerate batch preparation*, C_2 = ignore batch preparation.

A three-factor full-factorial with 2^3 designs was used. The number of scenarios is 2 (A_1, A_2) × 2 (B_1, B_2) × 2 (C_1, C_2) = 8, in which $A_2B_2C_2$ means that the FOUP is dispatched only through the traditional VD rule (level 4). In addition, the replication is set at 3 in determining the sum of squares due to error if the model includes all possible interactions (Montgomery 2001). Hence, the number of experiments performed is 24 [8 (scenarios) × 3 (replications) = 24]. Also, the simulation run is determined from the simulation time of four months at 24 hours a day, while the warm-up is set at two months, which is determined by a pre-simulation in which the stable trend of WIP can be obtained after two months.

5.6. *Simulation results*

The residual analysis of the indices measured by simulation satisfied the model assumptions (normality, independence of error term, and constant variance). The ANOVA analysis summarised in Table 3 indicates that A, B, C, and their interactions significantly affect the WO, CT, and BPT at the 95% confidence level, and stresses that addressing blocking, starvation, and batch preparation are critical to performance.

Further, it is necessary to examine any important interaction (Montgomery 2001), as well as the graphs of the highest-order significant interaction (ABC) to the indices. These data are shown in Figure 7. The slope in Figure 7(a) indicates that C_2 has little effect at A and B, but C_1 has a large effect at A and B. This also implies that C_1 is important to WO. The better WO would be obtained when A, B, and C are at A_1, B_1, and C_1. Analogical discussion points out that the best CT and BPT would be obtained when A, B, and C are at A_1, B_1, and C_1 respectively (Figures 7(b), 7(c)). In addition, Figure 7(c) states that C_1 keeps the shorter BPT at both A and B, and this result proves the idea in section 3.3.

In addition, the least significant difference (LSD) method was used for the post-hoc multiple comparisons to compare all pairs of the eight scenarios, as summarised in Table 4. The results show that the differences from the proposed strategies compared with ignoring the issues are statistically significant, and performances of $A_1B_1C_1$ outperform others. Besides, the percentage of BPT in the total process prepared time (includes serial and batch process) (BPT%) was also summarised. A large proportion of BPT, 49.5% ~ 65.9% indicates that it is necessary to reduce BPT by dispatching, and through this, will the adverse effects to the downstream of batch process be minimised.

Furthermore, a multiple-response method called desirability (Myers and Montgomery 1995) was used to integrate multiple indices into one. The method makes use of an objective function $D(X)$, called the desirability function

$$\boldsymbol{D} = (\boldsymbol{d}_1 \times \boldsymbol{d}_2 \times \ldots \times \boldsymbol{d}_n)^{\frac{1}{n}} = \left(\prod_{i=1}^{n} \boldsymbol{d}_i\right)^{\frac{1}{n}}$$

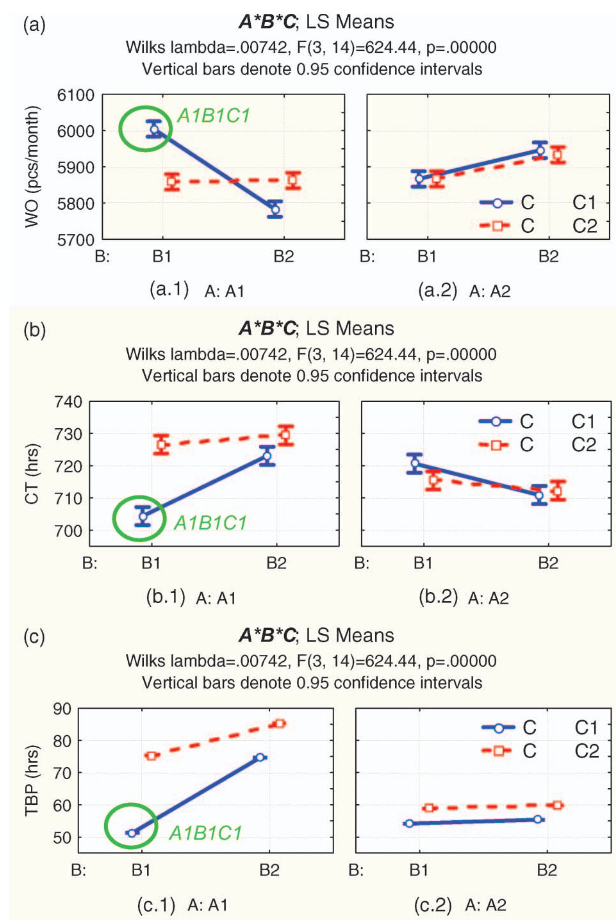

Figure 7. Graphs of the significant interaction.

Table 4. LSD and desirability for the transport strategies experiment.

Order	Scenario A	Scenario B	Scenario C	WO (pieces) mean	WO (pieces) rank	CT (h) mean	CT (h) rank	BPT (h) mean	BPT (h) (BPT%)	BPT (h) rank	Desirability
1	A_1	B_1	C_1	6004.2	A	704.4	A	51.3	(50.7%)	A	0.9275
7	A_2	B_2	C_1	5945.8	B	710.9	B	55.3	(53.3%)	C	0.7332
8	A_2	B_2	C_2	5933.3	B	712.3	BC	59.8	(55.7%)	E	0.6621
6	A_2	B_1	C_2	5866.7	C	715.4	C	58.8	(53.5%)	D	0.5247
5	A_2	B_1	C_1	5866.7	C	720.6	D	54.2	(49.5%)	B	0.4808
2	A_1	B_1	C_2	5858.3	C	726.6	EF	75.3	(61.5%)	G	0.2373
3	A_1	B_2	C_1	5783.3	D	723.1	DE	74.6	(62.4%)	F	0.1385
4	A_1	B_2	C_2	5862.5	C	729.4	F	85.3	(65.9%)	H	0.0476

A: Blocking, B: Starvation, C: Batch form; mean: average value measured from the replications; rank: different alphabet means the effects were significant at the 95% confidence level; BPT%: percentage of BPT in the total time of process prepares.

where n is the number of responses, $D(X)$ reflects the desirable range for each response (d_i), $0 \leqq d_i \leqq 1$, a geometric mean of all transformed responses. The desirability of each scenario is shown at the right side of Table 4. We can see that $A_1B_1C_1$ is the optimal transport strategy in response to the previous interactions analysis.

The following points have to be emphasised:

(1) Consideration of the tool status such as blocking, starvation, and batch process in vehicle-initiated dispatching (VSF) is required in order to smooth out production.
(2) *Avoid blocking* (A_1) and *avoid starvation* (B_1) are simultaneously required because the serious status that a tool's *starvation* caused by its *blocking* has to be obviated. Also, the *accelerate batch preparation* (C_1) should be combined with A_1 and B_1 to reduce the variances in cycle time, and to improve wafers output.

6. Conclusion and further research

This paper has addressed the issue of transport strategies in a 300 mm wafer fab with fully-automated manufacturing and material handling. Three transport strategies involved in VD, namely, the *avoid blocking, avoid starvation*, and *accelerate batch preparation*, were developed and implemented in the tool and the vehicle dispatching integration (TVDI) architecture. Accordingly, there are five levels of decision-making in TVDI, namely, *dispatching request, resource checking, candidate selection, dispatching rules*, and *result execution*. Particularly, *candidate selection* includes FST, FSS, and TSF which belong to TD, and FSV and VSF which belong to VD.

A simulation model abstracted from a fab in Taiwan and a three-factor full-factorial with 2^3 designs were used to evaluate the transport strategies. The results show that the factors A: blocking, B: starvation, and C: batch preparation significantly affect the performance of WO, CT, and BPT. Interaction analysis, LSD method, and desirability confirm that the combination of A_1: *avoid blocking*, B_1: *avoid starvation*, and C_1: *accelerate batch preparation* ($A_1B_1C_1$) has the best performance. The results also prove that the function of transport is not only to provide service to *production request* but also fully to support production like obviating production obstacles and avoiding capacity loss.

Therefore, the topic does not only involve the integration of two dispatching issues that are relatively independent today, but also further provides the solution for practitioners involved in dispatching software development. For practical implementation, MES could maintain a list of *prioritised moves* and *release* the most important move to the AMHS upon request, and the priorities could be continuously updated by MES based on the changes in production status that the authors proposed. After determining the appropriate transport strategies, the other operations in *candidate selection* can be further evaluated.

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Appendix 1. Process flow information.

	Production functions (area)										
	Layer s(t): step number (process time)										
	WS	TF	ET	DF	DF*	PH	IMP	CMP	CU	QC	Sub.
1	1(0.08)	7(5.45)	13(5.60)	3(1.12)	4(25.34)	14(2.83)	1(0.37)				43(40.78)
2		2(1.25)	10(4.80)		1(6.00)	10(2.00)	1(0.54)	1(1.03)			25(15.63)
3			2(1.10)			8(2.15)	5(2.13)				15(5.37)
4			2(1.10)			7(2.05)	5(1.99)				14(5.14)
5			2(1.10)			7(1.77)	5(1.98)				14(4.84)
6		1(0.94)	4(2.2)	2(1.85)	1(5.43)	7(2.05)	6(2.34)				21(14.80)
7		2(1.44)	3(1.20)	1(0.93)	2(11.02)	7(2.31)					15(16.89)
8		1(0.27)	8(5.15)	1(0.93)		13(2.13)	2(0.91)				25(9.38)
9			2(1.10)			7(1.21)	4(2.54)				13(4.85)
10			2(1.10)			4(1.33)	4(2.54)				10(4.97)
11			2(1.10)			7(1.49)	4(2.44)				13(5.03)
12			2(1.10)			4(1.33)	4(2.44)				10(4.87)
13			2(1.10)			7(1.21)	3(1.91)				12(4.22)
14		1(0.27)	8(4.55)	1(0.93)	3(16.33)	11(2.26)	2(1.78)				26(26.10)
15			3(2.10)			7(1.21)	5(4.61)				15(7.91)
16		1(0.50)	3(1.20)	1(0.93)		8(1.54)	4(3.37)				17(7.54)
17		7(4.88)	6(2.45)			12(2.84)	1(0.54)	1(1.03)			27(11.75)
18		11(4.95)	3(2.49)			14(1.67)		1(1.51)	1(0.10)		30(10.72)
19		11(5.00)	3(1.28)		1(4.22)	19(1.95)			4(2.21)		38(14.66)
20		1(0.29)	6(2.91)			10(1.52)					17(4.72)
21		11(5.27)	7(2.60)		1(4.22)	20(2.00)			4(2.21)		43(16.31)
22		1(0.29)	6(2.91)			10(1.52)					17(4.72)
23		11(5.27)	7(2.60)		1(4.22)	20(2.00)			4(2.21)		43(16.31)
24		1(0.29)	6(2.91)			10(1.52)					17(4.72)
25		11(5.00)	7(2.60)		1(4.22)	20(2.00)			4(2.21)		43(16.04)
26		1(0.29)	6(2.91)			10(1.52)					17(4.72)
27		11(5.24)	7(2.60)		1(4.22)	20(2.00)			4(2.21)		43(16.28)
28		1(0.29)	6(2.55)			10(1.52)					17(4.36)
29		12(5.86)	8(3.09)		1(4.22)	17(1.84)			4(2.21)		42(17.22)
30		4(2.16)	8(2.30)		1(4.22)	8(1.21)					21(9.90)
31			5(3.97)			4(1.99)					9(5.96)
32		1(1.07)	9(3.88)			2(1.18)					12(6.12)
33		2(0.57)	2(0.49)		1(5.50)	5(2.87)				2(0.17)	12(9.60)
Sub.	1	112	170	9	**19**	339	56	3	25	2	736
	(0.08)	(56.81)	(80.15)	(6.67)	**(99.17)**	(59.99)	(32.43)	(3.57)	(13.38)	(0.17)	(352.41)
%	0.14	15.22	23.1	1.22	**2.58**	46.06	7.61	0.41	3.4	0.27	100
	(0.02)	(16.12)	(22.74)	(1.89)	**(28.14)**	(17.02)	(9.2)	(1.01)	(3.8)	(0.05)	(100)

s: number of process step of each layer under different production functions; (t): total net process time (by hour) of each layer under different production functions; DF: *serial* step in diffusion process; DF*: *batch* step in diffusion process.