國立交通大學

工業工程與管理學系

博士論文

晶圓廠自動化物料搬運系統之
搬運策略模擬研究

Simulation Analysis of Transport Strategies for Automated Material Handling System in Wafer Fab

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摘要

在 300mm 晶圓廠搬運系統架構中，搬運車不僅限駛於單一製程中心，而可行駛於整廠。如此晶圓批(FOUP)需至下一製程機台加工時，可經由倉儲系統轉運至目的機台，或以機台對機台(tool-to-tool)的方式直接運送。搬運策略的發展在這新穎的搬運設施下顯的重要。本論文提出兩項搬運策略議題，並以國內某大晶圓廠為研究對象，利用系統模擬模式評估搬運策略績效。期望藉由合適搬運策略之發展，發揮該設施賦予彈性傳輸功能之效益。

第一項搬運策略，為派車時之搜尋範圍(Search Range，SR)指派議題。搜尋範圍之指派，為決定並限定某距離內之待搬運晶圓批(Waiting FOUP，WF)或閒置搬運車(Idle Vehicle，IV)，可考量被搬運或執行搬運命令，進而間接限制搬運車空車行進距離，使搬運資源有效利用。一個兩階段方法(two-phase approach)被提出。由模擬模式中之空車行進距離歷史記錄可得知，當派車被執行當下，系統中的待搬運晶圓批(WF)數或閒置搬運車(IV)數，會影響搬運車空車行進的距離；且當待搬運晶圓批數或閒置搬運車數越少時，空車行進距離越長。因此階段一為利用空車行進距離之歷史記錄，來訂定搜尋範圍之多個水準。階段二為，對階段一訂定之搜尋範圍水準進行評估。該多水準設定之精神，為派車時，根據不同待搬運晶圓批數或閒置搬運車數之系統況態下，給定不同的搜尋範圍。於本研究案例之實驗結果顯示，搜尋範圍的設定，顯著影響搬運績效，且較短搜尋範圍之設定，適用於搬運負荷較重之系統；搬運負荷較輕之系統，則適用較長之搜尋範圍。

第二項搬運策略，為因應全自動化製造之搬運模式，發展出之機台派工與搬運派車之整合指派(Integrated Dispatching，ID)架構。在該架構下，排除生產障礙及避免產能損失之三項搬運策略：避免壅塞(*avoid blocking*)、避免飢餓(*avoid starvation*)、加速集批準備(*accelerate batch preparation*)被被提出，輔以模擬評估於整合指派(ID)架構中。該整合架構涵蓋五階段決策程序，包括派工/派車要求、資源狀態確認、候選指派選擇、派工/派車法則、派工/派車執行。其中第三階段決策程序之候選指派選擇，包含五類選擇：晶圓批選擇機台(FST)、晶圓批選擇倉儲(FSS)、機台選擇晶圓批(TSF)、晶圓批選擇搬運車(FSV)、搬運車選擇晶圓批(VSF)。而所提出之三項搬運策略，被執行並評估於搬運車選擇晶圓批(VSF)中。於本研究案例之實驗結果顯示，所提出之三項搬運策略顯著影響系統績效，並使得績效指標有較佳表現。

關鍵字：搬運策略、派車、整合、自動化物料搬運系統、模擬

Simulation Analysis of Transport Strategies for Automated Material Handling System in Wafer Fab

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ABSTRACT

In the 300 mm wafer fab with connected loops track design, the vehicle can travel not just in one process center but all around the wide fab, and FOUP can be delivered either through stocker or tool-to-tool directly. Transport strategy development becomes important in this novel facility. In this dissertation, two issues of transport strategies were explored, and the simulation models abstracted from two wafer fabs in Taiwan were used to evaluate the transport strategies and attempt to bring this flexible transport configuration to a beneficial result.

The first issue, Search Range (SR) assignment, is to determine how far the waiting FOUPs (*WFs*) or idle vehicles (*IVs*) should be considered for transport task when dispatching occurs, and then indirectly limit the distance of vehicle's empty trip (*DVemp*) to make the vehicle work effectively. A two-phase approach with simulation has been developed to assign the Search Range (SR) for studying this idea. In phase I, the number of *WF* and *IV* in the system at the time of dispatching will affect *DVemp*. Further, the SR was assigned and evaluated based on the average and standard deviation of *DVemp* under different numbers of *WF* and *IV* in phase II. The results indicated that the SR significantly affects the performance, and a longer SR used in a light system is feasible; a shorter SR is applicable for a heavy system.

Second, the transport strategies named as Integrated Dispatching (ID) in Tool and Vehicle Dispatching Integrated (TVDI) architecture in a fully-automated manufacturing wafer fab were addressed. 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 further implemented in VSF. The simulation 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: Transport strategy, Dispatching, Integrated, AMHS, Simulation

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CHAPTER 1 INTRODUCTION

1.1 Motivation

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 manufacturing mentioned in Brain and Abuzeid [8], 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. 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 new transport mode (Kaempf [25], Kurosaki *et al*. [28], Bahri *et al*. [3]).

Therefore an Automated Material Handling System (AMHS) that moves wafer from one process equipment to another becomes a critical supporting system for wafer fabrication. The two major sub-systems for the AMHS are interbay and intrabays. Interbay is responsible for transporting wafer between different bays and intrabays take charge within bay transport. 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 1.1). 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 [49]).

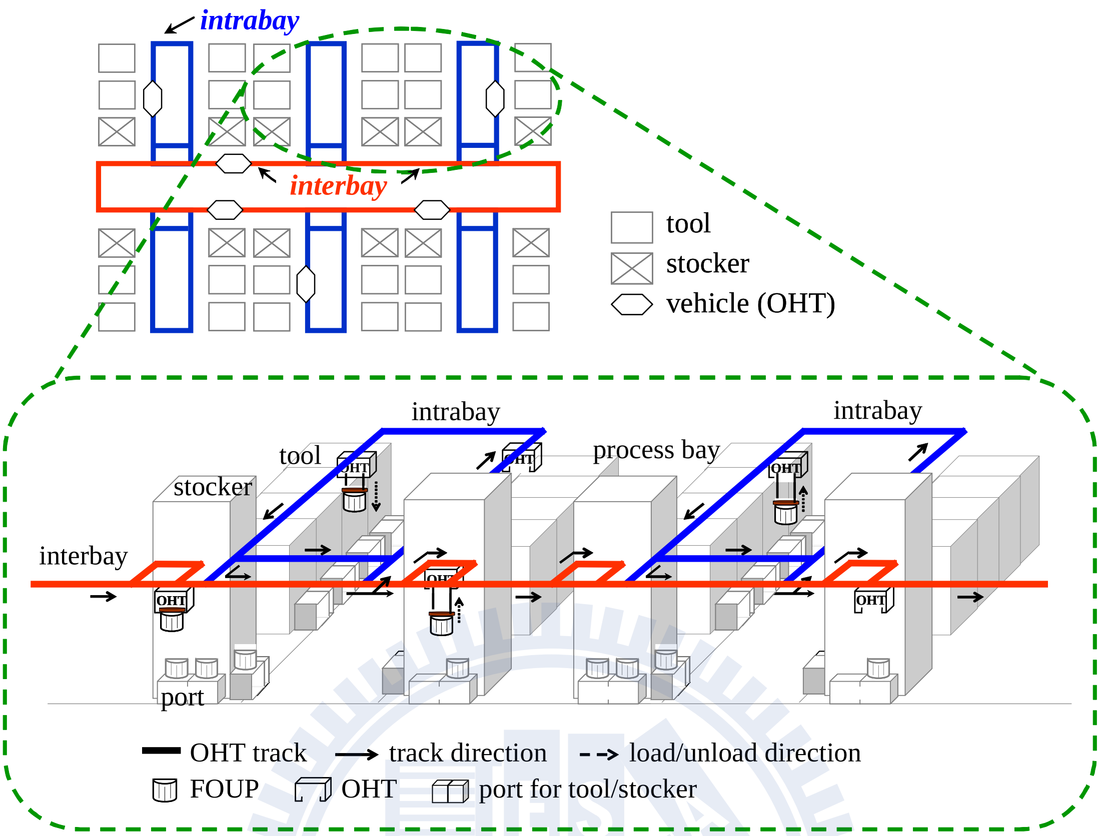


Figure 1.1 Configuration of a 300 mm wafer fab.

The issues surrounding the 300 mm AMHS can be classified as facility plan and transport operation. Once the hardware is determined, for maximum value the operation issues follow from the hardware investment and bring the facilities into full play. However, the previous issues regarding transport operation have been discussed separately for interbay or intrabay only, or even both systems, but the focal topic is just considered in respect to the loops. Nevertheless, the tracks are interlaced in the connected loops and vehicles can travel not just in one process bay, but all around the wide fab in order to execute direct tool-to-tool delivery. The more novel the facility plan brings the greatest challenge of integrating the transport and the production elements, particularly at the operational level, dispatching.

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 due 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. Moreover, Tool Dispatching (TD) involves the determination of which FOUP should be process first, given that many FOUPs are waiting to be processed. Vehicle Dispatching (VD) involves the determination of which FOUP to transport first, given that many FOUPs are waiting to be moved.

Furthermore, owing to the transport system becomes a critical supporting for wafer fab and the transport strategies adopted will affect the related performance, considering the suitable transport strategies to adopte in different shop floor situation is important. It’s the most important objective in this dissertation.

1.2 Objective

The purpose of this dissertation is to find the appropriate transport strategies for improving the system performance. The two transport operation issues in 300 mm fab in Taiwan were discussed. Under the given transport facilities, the transport strategies were developed to enhance each movement (or transport). That is, all movements of a FOUP are effective and valuable, so by using the proposed transport strategies.

The first issue named as Search Range (SR) assignment is to “determine how far the FOUP from the vehicle should be considered for transport when dispatching occurs, and then indirectly limit the empty travel distance required by vehicle to pick up the FOUP.” The range for search, whether too narrow or wide, will not only increase the time of FOUP to wait for being assigned or wait for vehicle to pick it up, but affect the utility of vehicle. Hance, an appropriate SR is required for dispatching. To achieve the objective, some key deliverables are identified as follow:

(1) To define the factor that might affect the range of search.
(2) To analyse the distance trend and distribution of a vehicle’s travel distance.
(3) To develop and evaluate levels of SR.
(4) To prove that SR is important to improve performance.
(5) To suggest a practicable SR for dispatching.

The second issue was named as Integrated Dispatching (ID). As the close interactions between production and transport in the fully-auto manufacturing environment, the functions of transport are not only to give service to the production requests, like moving FOUP to its downstream tool, but should carry out some *activities* to smooth the production. Hence, the strategies regard to obviate production obstacles or avoid capacity loss is required for production support. To achieve the objective, some key deliverables are identified as follow:

(1) To define the interaction between production and transport.
(2) To develop the transport strategies.
(3) To prove that transport strategt is important to enhance performance.
(4) To suggest the appropriate transport strategy.

1.3 Scope

Figure 1.2 shows that this research is focused on shop floor control especially the transport behavior. Due to the complicated manufacturing procedure of IC, some constraints have been applied to address the difficulties experienced during research:

1. The transport operation is focused on transport in wafer fab. The transport of back-end manufacturing, like wafer packaging and testing, is not considered.
2. This research is focused on transport operation. Production scheduling, release policy are not considered, and TD is only considered in ID issue.

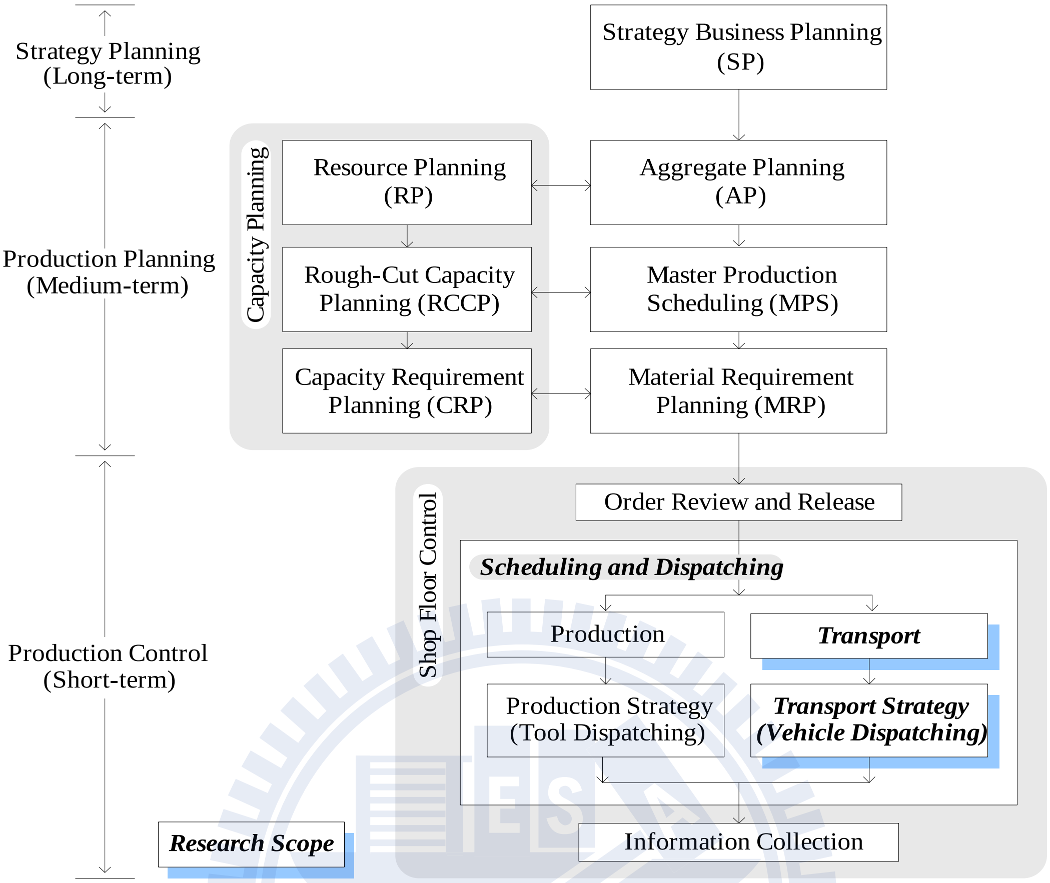


Figure 1.2 Architecture of production planning

1.4 Framework

The flowchart of the research approach is showen on the Figure 1.3. This research is to integrate of TD and VD to better the transport performance in wafer fab. Most researches are focused on either TD or VD in shop floor control. However these control strategies have significant interactions, and should be modified accordingly for the dynamic environment. Therefore, the appropriate integrated strageties will be suggested through the research approach. The areas of shadow on the Figure 1.3 represent the works will be done by this research.

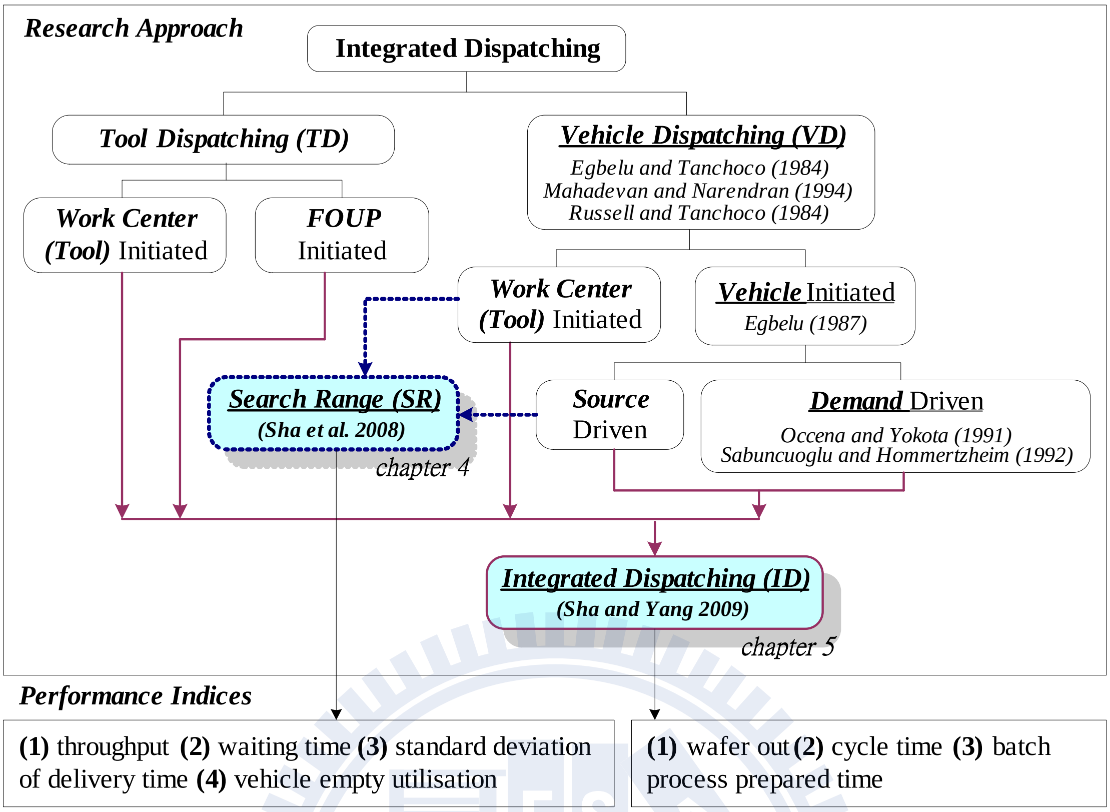


Figure 1.3 Research approach

The research framework is depicted in Figure 1.4. In order to undertake a thorough inquiry into transport strategy, a comprehensive literature review is conducted, including the evolution of a facility plan and consideration of the operational issues in transport. Also, the issues derived from the AGV system might lead to inspiration to solve similar problems. The production literature is reviewed in order to understand the characteristics and restrictions in these areas, with domain knowledge acquired from discussion with related staff in the fab. Once the research problem is defined and the objective is set, the research approach is developed. The tools applied are eM-Plant™ [17] for simulation model construction, and Design Expert [56] for design of the experiment and results analysis. Further, the transport strategy is evaluated throughout this research and practicable strategies are suggested.

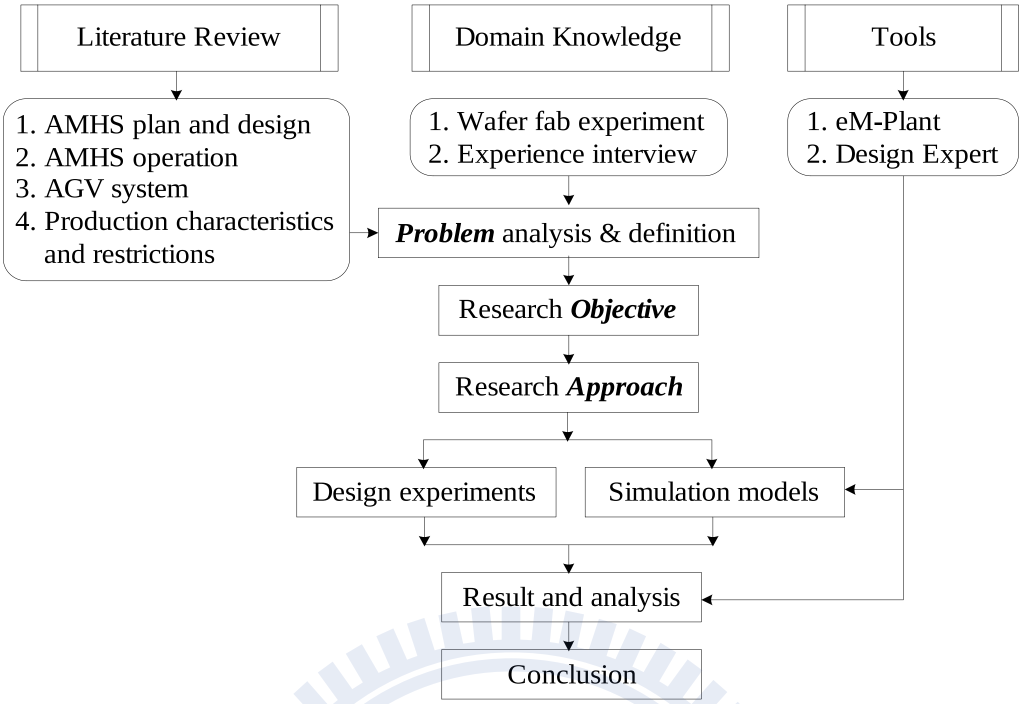


Figure 1.4 Research framework

The remainder of this dissertation is organized as follows. Chapter 2 will review the related literature. Chapter 3 will briefly describe a 300 mm transport system in the wafer fab. The first issue about SR assignment is addressed in Chapter 4, and the second issue about ID is presented in Chapter 5. The conclusion and achievement are presented in the final chapter.

CHAPTER 2 LITERATURE REVIEW

The track layout and transport facility in 300mm fab is a breakthrough. Once the hardware is determined, the operational issues follow which need to be evaluated with the aim of finding the appropriate strategy for best performance and maximum value from the hardware investment. The related issues about facility plan and transport operation displayed in Figure 2.1 were reviewed. Further, due to understand the interactions between transport and production, literatures about production dispatching were briefly reviewed.

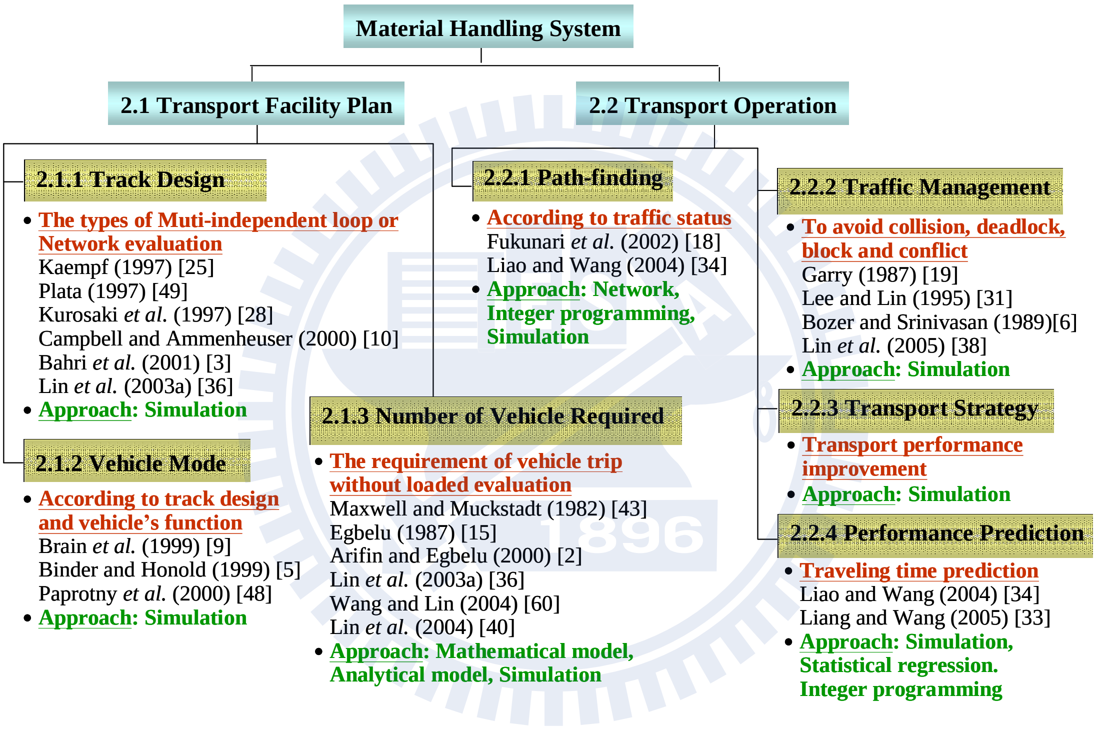


Figure 2.1 Issues reviewed in material handling system

2.1 Transport Facility Plan

2.1.1 Track Design

From the economic and ergonomic requirement, the track layout in wafer fab is developed from multiple independent loops to overhead connected loops generally. Kaempf [25] illustrated the different overhead AMHS architectures included interbay and intrabay connected with stocker and turntable; hybrid loop linking two bays; parking loop and vehicle dismount station; end-of-bay and within-the-bay stocker. From that facility, the pod can be direct and manual delivered to process tools. Plata [49] introduced a zero footprints in transport where the interbay system and intrabay system may be linked to provide a matrix of transport capabilities. Kurosaki *et al*. [28] compared the performance of isolated lines and interconnected lines, with the result that the lead time of the interconnected line was better than the isolated line. Campbell and Ammenheuser [10] showed the overhead 300mm AMHS with the separated interbay and intrabay loops. But the bay-to-bay transport must travel via stocker operation. Bahri *et al*. [3] compared the unified and segregated AMHS for 300mm fabs, with the results showing that system reliability of the former would be better and provided shorter delivery times. Lin *et al.* [36] introduced the connecting transport for 300 mm AMHS, combining an interconnected line with a connected track in front of intrabay. Further, the wafer delivery time can be reduced under this configuration.

2.1.2 Vehicle Mode

The types of vehicle must be evaluated synchronously while evaluating the track layout. Brain *et al.* [9] introduced types of vehicle for different applications: overhead shuttle (OHS) and overhead hoist transport (OHT) are used to overhead monorail AMHS; continuous flow transport (CFT) conveyor is a type of conveyor AMHS; floor based vehicles included automated guided vehicle (AGV), rail guided vehicle (RGV) and person guided vehicle (PGV). Also, Binder and Honold [5] indicated that AGV and RGV are set within the process bay, and PGV is utilized to transport manually. The OHT with a hoist system is used to transport the FOUP between stocker systems. Paprotny *et al.* [48] evaluated the alternatives CFT and OHT. Their study discovered that the average delivery time of OHT was half that of CFT, but that the OHT system was more variable than CFT because its allocation was less certain.

2.1.3 Number of Vehicle Required

The number of vehicles required follows for work out the transport capability, and this is extended from the same issue in traditional AGV system. Generally, the approach with mathematical model, analytical model and simulation are used. Maxwell and Muckstadt [43] defined a mathematical model with a shortest route algorithm to measure the minimum travel time of empty vehicles for obtaining the minimum vehicle number. But the algorithm did not account for blocking or congestion in the system. Egbelu [15] proposed four analytical approaches to calculate the number of vehicles required in an AGV system. The main idea is to estimates the inexact time required like the empty travel time and time affected by traffic. Arifin and Egbelu [2] developed an analytical model using regression to estimate the number of vehicles required in a facility, and identified a total of 32 different facility layouts drawn from published papers involving AGVs for defined significant factors. Further in the wafer fab, Lin *et al.* [36] addressed a decomposing approach to determine the minimum number of vehicles for different vehicle types of 300mm connecting transport AMHS. Wang and Lin [61] used the simulation and response surface method to determine the vehicle numbers in an intrabay system in photoarea. Lin *et al.* [40] investigated the number of vehicles in a double-loop interbay system through simulation, and used response surface methodology for estimating the optimum vehicle number.

2.2 Transport Operation

2.2.1 Path-finding

Usually, the path with the shortest distance, which does not consider the time delay in traffic, is designated for vehicle to travel. However, it might not the shortest time path to the destination. This issue attempts to determine the travel path according to the time-dependent in environment. In the wafer fab, Fukunari *et al.* [18] proposed a dynamic path-finding algorithm with the idea of node penalty. A node's type was classified as routing, loading/unloading and charging node, and the penalty was defined as the node crossing time obtained from historical data and the number of vehicles in the queue. Further, the path with avoiding congestion was determined using the shortest-path algorithm. The integer programming used in Liao and Wang [34] determined the path of shortest delivery time in loop-to-loop AMHS, in which the delivery time for each loop was estimated by neural network with simulation.

2.2.2 Traffic Management

The issues of traffic management are focused on avoiding the collision, deadlock, block and conflict problem during transport. Three types to manage traffic for avoid collision in AGVs introduced by Garry [19] are zone control, forward sensing and combination control. In which zone control is to segment the path into separate zones, and only one vehicle is permitted in a given zone at a time; forward sensing is to use a sensing system onboard the vehicle to detect the presence of a vehicle in front of it. In combination control, forward sensing may use in long runs while zone control would be used in the divergence-path and convergence-path area. Further, competing for causes deadlock or sharing limited resources like limited buffer and guide paths in a system and then the blocking of material flow and circular wait for each other occurs. Lee and Lin [31] proposed an algorithm based on Petri Nets to predict and to avoid deadlock in zone-control uni-directional AGVs. In this study, two phases include deadlock prediction, which is to generate future states to predict whether a deadlock occurs, and traveling decision, which is to prevent vehicle forming a circular wait. Furthermore, the tandem AGVs proposed in Bozer and Srinivasan [6] is developed for “divide and conquer” to better the complex traffic control in traditional AGVs. The principle is to divide the workstation into several non-overlapping, independent and single loops with the uni-direction track. The only one vehicle is implemented in each loop so that the problem of collision, deadlock, block and conflict can be eliminated. However, the cross loop transport needs to transit through the designed transit station, which exist other issues for studying. Besides, in the wafer fab, Lin *et al.* [38] proposed four strategies for controlling the upper and lower limits of the number of vehicles in the intrabay to avoid congestion and let vehicles be fully utilized. The simulation result showed that these strategies significantly improve the performance.

2.2.3 Transport Strategy

The transport strategy is developed under the give facility for improving performance, and the simulation approach is uaually used to evaluation. The related literatures were abstracted the in Table 2.1 with the time sequence of publication, and strategies/dispatching rule in literatures were made a classification and listed in Table 2.2. The review of this topic was classified as three sections: *classification*, *comparison* and *evaluavtion*. New strategies proposed and compared to the existing strategies were reviewed in *comparison*, while the existing strategies evaluated in different environment or system condition were reviewed in *evaluation*.

A. Classification of Transport Strategy

Egbelu and Tanchoco [16] classified the Vehicle Dispatching (VD) in AGV as workcenter-initiated and vehicle-initiated, and multiple rules associate with the classifications were presented. Egbelu [15] further classified the vehicle-initialed dispatching into source driven (push) and demand driven (pull), and the vehicle-initialed rules in Egbelu and Tanchoco [16] were classed as source driven rules. A new dispatching classification was presented in Le-Anh and de Koster [30]. The dispatching systems is classified into decentralized and centralized system, and four types of rules in centralized system included single-attribute, multi-attribute, hierarchical rules and look-ahead or vehicle reassignment. Also the authors addressed the general objectives included (a) minimizing load waiting time (b) maximizing system throughput (c) minimizing queue length and (d) guaranteeing a certain service level at stations.

B. Comparison of Transport Strategy

A vehicle-initiated rule, modified first come first serve (MFCFS) was proposed in Egbelu and Tanchoco [16]. In this rule, the saved call (move request) and the time the call was generated were used for further vehicle assignment, and a department can have only one outstanding saved call for dispersing the traffic intensity of this department. The result of comparison many workcenter-initiated and vehicle-initiated rules indicated that the performance was sensitive only to the vehicle-initiated rule for busy shops, and MFCFS performed better than other rules. A heuristic rule first encountered first served (FEFS) in simple loop AGV was proposed in Bartholdi and Platzman [4]. In the simple loop, vehicle circulates a loop continuously, and picks up the first load encountered whenever it has available space, which will be delivered whenever reaches their destinations. Rule FEFS compared with first come first served (FCFS), pick up task at the longest queue (TLQ) and pick up task closest to its destination (TCD) showed that FEFS can reduce waiting time.

Egbelu [14] proposed a demand driven rule (DEMD) for vehicle to select one part which can eliminate tool's blocking or avoid low utilization. The simulation for comparison the source driven rules and DEMD showed that DEMD performed better. The maximum demand rule (MD) in the JIT system was proposed in Occena and Yokota [47]. The authors set the threshold values for both input and output queues, and vehicle executes the transport only when exists a move demand from a deposit station and a part in the corresponding pick-up station. The result compared MD and DEMD (Egbelu [14]) showed that MD performed better both on throughput and average inventory. For a photobay in a 300 mm fab, Lin *et al.* [35] proposed a hybrid push-pull dispatching strategy using the concept of look-ahead (push mechanism) and look-back (pull mechanism) to determine the next task for vehicle according to the states of upstream and downstream tool. Under this strategy, the WIP and cycle time can be improved. Also the numbers of input/retrieve in stocker and unnecessary transport can be decreased.

Sabuncuoglu and Hommertzheim [52] developed a dynamic dispatching algorithm (DDA) for scheduling both machine and AGV. Four hierarchical logics included in AGV dispatching were push logic for critical stations, buffer logic for central buffer, pull logic for idle workstations and push-pull logic for the most appropriate workstation and part, and operation time and expected waiting time on the next operation were considered in machine dispatching. The result compared DDA and SPT/LQS, SPT/SDT, MOD/SDT, MOD/LQS indicated that DDA outperformed on mean flow-time and mean tardiness at varying machine load levels and queue capacity. The rule BID with the bidding function which developed to avoid outgoing buffer to become blocking and incoming buffer to become starving, also attempts to reduce the distance of vehicle's empty trip was proposed in Hwang and Kim [22]. The evaluation of BID with STTF and Mod FCFS showed that BID outperformed other rules on throughput especially when system loading increased. Multi-attribute decision rule (MADR) with attribute weights continuously modified using the neural network approach was proposed in Jeong and Randhawa [23]. The attributes included empty trip distance, remaining spaces in input and output buffers. The proposed rule was compared with STT/STD, MRIQ and MROQS, and the result showed that adapting the attribute weights based on system status can improve the overall performance.

Two vehicle-initiated rules with vehicle reassignment were proposed in Bozer and Yen [7]. In rule modified shortest travel time first (MOD STTF), the average distance of loaded trip is set as threshold to determine if the assigned task is committed or else vehicle might be released for others task. Besides, rule B2D2 let all vehicles place a bid based on its current workload when a movement request issues, and allowed vehicle to have more than one committed tasks. The rule MOD STTF and B2D2 were compared with rule STTF and Mod FCFS. The result showed that reassignment-based rules perform better under different layouts, and B2D2 has the strongest performance. The comparison of single-attribute and multi-attribute dispatching rules in the warehouse were addressed in Le-Anh and De Koster [29]. The single-attribute rules included MODFCFS, STDF, NVF_R, NVF_RC. The vehicle empty travel distance and the load waiting time were considered in multi-attribute rules: multi-att, multi-mod and combi. The concept of moving vehicle reassignment applied in NVF_R, NVF_RC and Combi indicated that vehicle might be reassigned while the vehicle empty travel distance is longer than a distant threshold. The simulation result showed that NVF_RC, NVF_R, Combi performed well on minimize the load waiting time, and MODFCFS, Multi-att, Multi-mod and Combi performed well on minimize the maximum load waiting time. The general multi-attribute metric (MAM) of vehicle reassignment was proposed in Kim *et al.* [26]. In this research, the reassignment is only considered whenever the distance between the vehicle and the load is shorter than the distance between the vehicle originally assigned. Further the empty trip distance and waiting time of load would be taken into account in the metric to determine the appropriate load. The result of the rule with MAM compared to STD, B2D2 and NVF_RC showed that reassignment-based rules out performed than STD, and the MAM is the best.

Lin *et al.* [36] developed the transport strategy by classifying the vehicle into four types, Type-A, B, C, D to service the respective area in the connecting transport AMHS. Further the tool-to-tool delivery can be accomplished by three transport methods which are the combination of vehicle type, including Type-A and B, Type-A and C, Type-A and D. Furthermore, transport strategy was defined as mixture of three transport methods in Lin *et al.* [37] and the optimum mixture percentage wase obtained by response surface methodology. The simulation result indicated that the transport method Type-A and D performed better on travel time, Type-A and C performed better on throughput and Type-A and B performed better on utilization. Lin *et al.* [41] extended the previous study in Lin *et al.* [37], vehicle can change its type according to different task request. In this research, flexible transport strategy leads to shorter empty vehicle trips, and more efficient dispatching.

The rule preemptive highest priority job first (PHP) to reduce lot cycle times of priority lots in a single loop 300 mm AMHS was developed in Wang and Liao [59]. Under PHP, any ongoing transports which block the OHT dispatched by highest priority job will be pending until job completes. The simulation result which compared the rule PHP, NPH (highest priority job without privilege on other OHTs) and NJF showed that PHP can reduce cycle times of priority lots with acceptable time delay on regular lots. Wang and Liao [60] developed an OHT policy, differentiated preemptive dispatching (DPD) to enhance the serve of hot lot by reducing the frequently blocking by normal lots transport. The DPD rule can re-dispatch the nearest empty OHT to the priority lot and prohibit loading/unloading for a non-priority lot if the operation would block the priority lot. The simulation result showed that DPD reduces the average delivery time of hot lots by 24.9%.

De Koster *et al.* [13] proposed the rules using the pre-arrival information and the time truncation in distance in the warehouse, production plant and transshipment terminal environment. Four decision points with the associate rules in multiple-load AGV were identified in Ho and Chien [21]. The first problem is to determine whether the next task of AGV is to pickup or delivery; the second is to determine which delivery station the AGV should visit if the next task of AGV is determined to delivery; the third is to determine which pickup station the AGV should visit if the next task of AGV is determined to pickup; the forth is to determine which job should be picked up from the output queue. The best combination rule suggested by simulation for the four problems is DTF, SD, GOQ, ID respectively. The Search Range (SR) for dispatching under the connected loop AMHS was proposed in Sha *et al.* [54]. The idea is to ignore the waiting FOUPs which are too far from the vehicle, so that the distance of vehicle's empty trip and the time for FOUP to wait for being picked it up can be reduced. The simulation result indicated that longer SR is applicable in a light system, and in a heavy system the shorter SR is.

C. Evaluation of Transport Strategy

Four vehicle-initiated rules for lift truck dispatching in job shop were evaluated in Russell and Tanchoco [50], including largest number in queue (LNQ), longest waiting time (LWT), preferred order by nearest load (POR) and random assignment (RAN). The simulation results showed that the LNQ was the most stable rule to the length of queue at the pickup stations. Yim and Linn [64] evaluated the vehicle-initiated rule in push-based AGVs and pull-based AGVs. The proposed vehicle-initiated rule considered two sections were part selection rule: longest waiting time (LWT), minimum remaining outgoing queue space (MROQ), and process selection rule: longest inter-arrival time (LIT), maximum remaining incoming queue space (MRIQ). Further the decision sequence in push-based AGVs was part selection then process selection, while in pull-based AGVs was process selection then part selection. The simulation result compared the push-based with pull-based dispatching showed that they performed equally well on average output rate. Mahadevan and Narendran [42] evaluated dispatching rules in multi-vehicle FMS including least utilized vehicle (LVV), nearest vehicle (NV), first available free vehicle (FAFV), fixed path vehicle dispatch (FPVD) and modified fixed path vehicle dispatch (MFPVD). The simulation result showed that NV performs the best, and the cycle time is reduced by 40% in MFPVD that in the FPYD. Sabuncuoglu [51] evaluated the combination of machine rules and AGV rules under different system loading, queue capacity and down time. Machine scheduling rules included SPT, SPT.TOT, SPT/TOT, LWKR and FCFS; AGV rules including FCFS, LQS, STD and LWKR. Simulation result showed that SPT-STD out performed others rule on mean flow time in general, and LQS responded faster than STD to blocking if queue capacities reduced and down time increased.

Lin *et al.* [39] outlined dispatching strategies in a double loop interbay with three decision points: loop selection, cassette-initiated and vehicle-initiated rule. The results showed that the shortest distance (SD) for loop selection, the nearest vehicle (NV) for cassette-initiated dispatching and foremost encounter first served (FEFS) for vehicle-initiated dispatching outperformed the others. Jimenez *et al.* [24] evaluated the decision problem consists of selecting inner or outer rail for inter-bay transport and selecting the lifters for inter-floor transport in the interbay with two-floor layout. The simulation result show that the strategy based on the shortest distance and the fewer number of waiting lots in the path can minimize average transfer time. Four dispatching decision points and the associate rules in fab identified in Min and Yih [44] were selection lot by critical machine: FCFS, SRPT, EDD and CR; selection lot by non-critical machine: FCFS, SRPT, EDD and CR; selection lot by stocker: FRFS, IBF, LRS, EDD, SRPT and CR and selection lot by vehicle: FRFS, LRS, EDD, SRPT and CR. The authors dynamically adjusted the rule combination using competitive neural network and resulted in the superior performance to others method.

Table 2.1 Literature of transport strategy summary

No	**Author**	**Appl.**	**Abstract (Strategy)**	**Result**	**Performance Criteria**
[16]	Egbelu and Tanchoco (1984)	FMS	*(1) Dispatching classification* ✓ Workcenter-initiated ✓ Vehicle-initiated *(2) Strategy Comparison* ✓ Workcenter-initiated: RV, NV, FV, LIV, LUV ✓ Vehicle-initiated: (a) **Modified first come first serve (MFCFS)** (b) RW, STT/D, LTT/D, MOQS, MROQS, ULSAT	• Vehicle-initiated rule was significant in busy shop • **MFCFS** performed better than other rules	(a)Throughput
[50]	Russell and Tanchoco (1984)	Job shop	(1) Vehicle-initiated rules for lift truck dispatching (2) *Strategy Evaluation* ✓ Rules: LNQ, LWT, POR, RAN	• LNQ outperformed in (e) • No difference in other rules in indices	(a) Mean flow time (b) Machine utilization (c) Truck utilization (d) Max queues at delivery stations (e) Max queues at pickup stations
[14]	Egbelu (1987)	FMS	*(1) Vehicle-initiated rule Classification* ✓ Source driven ✓ Demand driven *(2) Strategy Comparison* ✓ **Demand driven (DEMD) rule** (tie: MFCFS-NV) ✓ MFCFS-NV, MROQS-NV, STT/D-NV	• **DEMD**-NV performed better than other source driven rules	(a) Throughput (b) Time required to a fixed number of parts (c) Vehicle number required
[4]	Bartholdi and Platzman (1989)	FMS	(1) Heuristic rule in single loop *(2) Strategy Comparison* ✓ **First encountered first served (FEFS)** ✓ FCFS, TLQ, TCD	• **FEFS** out performance	(a) Average waiting time
[47]	Occena and Yokota (1991)	FMS	(1) Threshold values for queues *(2) Strategy Comparison* ✓ **Maximum demand (MD) rule** ✓ DEMD (Egbelu 1987)	• **MD** out performance	(a) Throughput (b) Average inventory
[52]	Sabuncuoglu and Hommertzheim (1992)	FMS	(1) Hierarchical logics in AGV dispatching and time-related attributes in machine dispatching *(2) Strategy Comparison* ✓ **Dynamic dispatching algorithm (DDA)** ✓ SPT/LQS, SPT/SDT, MOD/LQS, MOD/SDT	• **DDA** outperformed at varying machine loading and queue capacity	(a) Mean flow-time (b) Mean tardiness

Table 2.1 Literature of transport strategy summary (cont.)

No	Author	Appl.	Abstract (Strategy)	Result	Performance Criteria
[64]	Yim and Linnt (1993)	FMS	(1) Vehicle-initiated rule ✓ Part selection: LWT, MROQ ✓ Process selection: LIT, MRIQ *(2) <u>Strategy Evaluation</u>* ✓ Push-based: part selection➔ process selection ✓ Pull-based: process selection➔ part selection	• Push-based and Pull-based performed equally well	(a) Average output rate
[42]	Mahadevan and Narendran (1994)	FMS	(1) Vehicle dispatching in multi-vehicle FMS *(2) <u>Strategy Evaluation</u>* ✓ LUV, NV, FAFV, FPVD, MFPVD	• NV performs the best • In MFPVD, the cycle time is reduced by 40% that in FPYD	(a) Cycle time (b) Queue length (c) AGV utilization (d) Waiting time (e) Throughput
[7]	Bozer and Yen (1996)	FMS	(1) Vehicle reassignment (distance threshold) *(2) <u>Strategy Comparison</u>* ✓ **Modified shortest travel time first (MOD STTF)** ✓ **Bidding-based dynamic dispatching (B2D2)** ✓ STTF, Mod FCFS	• **MOD STTF** and **B2D2** performed better • **B2D2** has the strongest performance	(a) Vehicle utilization (b) Time in system (c) Queuing time (d) Maximum output queue
[22]	Hwang and Kim (1998)	FMS	(1) Bidding with status of incoming/outgoing buffer and distance of vehicle's empty trip *(2) <u>Strategy Comparison</u>* ✓ **Bidding (BID) rule** ✓ STTF, Mod FCFS	• **BID** outperformed especially in heavy system loading	(a) Throughput
[51]	Sabuncuoglu (1998)	FMS	(1) Rules in different loading, queue capacity, down time *(2) <u>Strategy Evaluation</u>* ✓ Machine scheduling: SPT, SPT.TOT, SPT/TOT, LWKR, FCFS ✓ AGV scheduling: FCFS, LQS, STD, LWKR	• SPT-STD outperformed in general • Queue capacity reduced, down time increased, LQS responds faster than STD to blocking	(a) Mean flow time
[23]	Jeong and Randhawa (2001)	FMS	(1) Multi-attribute with weights continuously modified *(2) <u>Strategy Comparison</u>* ✓ **Multi-attribute decision rule (MADR)** (a) Empty trip distance (b) Remaining spaces in input/output buffers ✓ STT/STD, MRIQ, MROQS	• Performance improved by adapting weights dynamically	(a) Time in system (b) Unloaded travel time (c) Blocking time (d) WIP

Table 2.1 Literature of transport strategy summary (cont.)

No	Author	Appl.	Abstract (Strategy)	Result	Performance Criteria
[39]	Lin *et al.* (2001)	Fab	(1) Three dispatching decision in *double loop interbay* *(2) Strategy Evaluation* ✓ Loop selection: SD, WN, WD, WR ✓ Cassette-initiated: NV ✓ Vehicle-initiated: FEFS, LWT	• SD/NV-FEFS outperformed the others	(a) Transport time (b) Waiting time (c) Throughput (d) Vehicle utilization
[24]	Jimenez *et al.* (2002)	Fab	(1) Loop and lifter selection in two-floor interbay *(2) Strategy Evaluation* ✓ Rail selection: SD, FWL, SD-FWL, RAN ✓ Lifter selection: SD, FWL, SD-FWL, RAN	• Shortest distance and fewer number of waiting lots performed better	(a) Average delivery time (b) Std. delivery time
[36]	Lin *et al.* (2003a)	Fab	(1) Types vehicle in connecting transport fab ✓ Type-A, B, C and D serve its own area *(2) Strategy Comparison* (compared to Lin *et al*. 2003b) ✓ **Fixed vehicle type dispatching (FVT)** ✓ NV-FEFS (3) Transport methods ✓ (a) Type-A, B (b) Type-A, C (c) Type-A, D	• Four vehicle types serve in connecting transport environment	
[37]	Lin *et al.* (2003b)	Fab	(1) Transport strategy (extent Lin *et al*. 2003a) *(2) Strategy Comparison* ✓ **Mixture fixed vehicle type dispatching (MFVT)** ✓ NV-FEFS (3) Optimum % obtained by response surface methodology	• Travel time: Type-A, D • Throughput: Type-A, C • Utilization: Type-A, B	(a) Travel time (b) Throughput (c) Utilization
[44]	Min and Yih (2003)	Fab	(1) Four decision points in fab interbay *(2) Strategy Evaluation* (Selection lot) ✓ By critical machine: FCFS, SRPT, EDD, CR ✓ By non-critical machine: FCFS, SRPT, EDD, CR ✓ By stocker: FRFS, IBF, LRS, EDD, SRPT, CR ✓ By vehicle: FRFS, LRS, EDD, SRPT, CR (3) Competitive neural network determine combination	• Dynamically adjust rules is superior	(a) Mean of flow time (b) Mean of slack time (c) Mean of total (d) Remaining process time
[59]	Wang and Liao (2003)	Fab	(1) Reduce cycle times of priority jobs (one loop) *(2) Strategy Comparison* ✓ **Preemptive Highest Priority Job First (PHP)** ✓ NJF	• PHP is effective in reducing cycle times of priority jobs • Acceptable time delay on regular jobs	(a) Minimize the transport delay of high priority lots

Table 2.1 Literature of transport strategy summary (cont.)

No	Author	Appl.	Abstract (Strategy)	Result	Performance Criteria
[13]	De Koster *et al.* (2004)	Other	(1) Pre-arrival information and time truncation in distance *(2) Strategy Comparison* ✓ **Dispatching with pre-arrival Information (DPI)** ✓ **Nearest-Vehicle-First with Time Priority (NVFTP)** ✓ Application (a) Warehouse: WLD, LLD, DPI (b) Production plant: DD, C100FCFS, DPI (c) Transshipment terminal: LLD, DPI ✓ Common rules: NWF, NVF, MODFCFS, NVFTP	• Distance-based rules (NVF, NWF) performs better on the load waiting time	(a) Load waiting time (b) Maximum load waiting time (c) Vehicle utilization (d) Maximum number of critical queue
[41]	Lin *et al.* (2004)	Fab	(1) Vehicle type exchanged *(2) Strategy Comparison* ✓ **Mix virtual vehicle type dispatching (MVVT)** ✓ MFVT (Lin et al. 2003b)	• Time spent waiting for an empty vehicle is reduced	(a) Throughput (b) Transport time (c) 95% transport time (d) Waiting time
[60]	Wang and Liao (2004)	Fab	(1) Reduce frequently blocking of hot lots transport *(2) Strategy Comparison* ✓ **Differentiated Preemptive Dispatching (DPD)** ✓ **Non-preemptive highest priority job first (NPH)** ✓ NJF	• DPD reduced average delivery time of hot lots by 24.9%.	(a) Average delivery times
[29]	Le-Anh and De Koster (2005)	Other	(1) Single-attribute and Multi-attribute rules in warehouse *(2) Strategy Comparison* ✓ Single-attribute: (a) Nearest vehicle first with re-assignment (NVF_R) (b) Nearest vehicle first with re-assignment and cancellation (NVF_RC) (c) MODFCFS, STDF ✓ Multi-attribute: (a) Modified multi-attribute (Multi-mod) (b) Combined dispatching (Combi) (c) Multi-att	• NVF_RC, NVF_R, Combi performed well in index (a) • MODFCFS, Multi-att, Multi-mod, Combi performed well in index (b)	(a) Minimize the load waiting time (b) Minimize the maximum load waiting time

Table 2.1 Literature of transport strategy summary (cont.)

No	Author	Appl.	Abstract (Strategy)	Result	Performance Criteria
[21]	Ho and Chien (2006)	FMS	(1) Four decision problems in multiple-load AGV *(2) Strategy Comparison* ✓ Task-determination: Load-ratio (LR), DTF, PTF ✓ Delivery-dispatching: SD, SRPT, CM (SD+SRPT), SIQ, LTIS, LTOV, EDT, LET, SST, RDM ✓ Pickup-dispatching: SD, GOQ ✓ Load-selection: ID	• Combination DTF-SD-GOQ-ID performed better	(a) Throughput (b) Mean lateness
[30]	Le-Anh and De Koster (2006)	FMS	*(1) Dispatching-rule Classification* (2) Online dispatching ✓ Decentralized system ✓ Centralized system (a) Single-attribute dispatching rules (b) Multi-attribute dispatching rules (c) Hierarchical dispatching rules (d) Look-ahead period, Vehicle reassignment	• A new dispatching-rule classification	Objectives: (a) Minimizing load waiting time (b) Maximizing system throughput (c) Minimizing queue length (d) Service level guaranteeing
[35]	Lin *et al.* (2006)	Fab	(1) Hybrid push/pull (PP) in a photobay *(2) Strategy Comparison* ✓ **Hybrid push/pull (PP) rule** ✓ FEFS	• PP reduce WIP and cycle time under high arrival rate	(a) Throughput (b) Cycle time (c) WIP (d) Delivery time (e) 95% delivery time (f) Transport time (g) Transport complete (h) Vehicle utilization
[54]	Sha *et al.* (2006)	Fab	(1) Search range for vehicle dispatching *(2) Strategy Comparison* ✓ **SR-based dispatching (SR)** ✓ FEFS	• longer SR in light system, shorter SR in heavy system	(a) Throughput (b) Waiting time (c) Std. delivery time (d) Vehicle empty utilisation
[26]	Kim *et al.* (2007)	Fab	(1) Vehicle reassignment *(2) Strategy Comparison* ✓ **Multi-attribute metric (MAM) dispatching** ✓ STDF, B2D2, NVF_RC	• Reassignment-based rules out performed than STD • Proposed is the best	(a) Queue size (b) Lead time (c) Std. lead time (d) Vehicle status

Table 2.2 Dispatching rule summary

No	Rule		Authors	Workcenter-initiated	Vehicle-initiated		Distance-related	Time-related	Queue-related	
					Source	Demand			Input	Output
● **WorkCenter-Initiated Dispatching**										
1	FAFV	First available free vehicle	Mahadevan and Narendran (1994)	V				V		
2	FPVD	Fixed path vehicle dispatch	Mahadevan and Narendran (1994)	V			V			
3	FV	Farthest vehicle rule	Egbelu and Tanchoco (1984)	V			V			
4	LIV	Longest idle vehicle rule	Egbelu and Tanchoco (1984)	V				V		
5	LUV	Least utilized vehicle rule	Egbelu and Tanchoco (1984)	V			V	V		
6	MFPVD	Modified fixed path vehicle dispatch	Mahadevan and Narendran (1994)	V			V			
7	NV	Nearest vehicle rule	Egbelu and Tanchoco (1984)	V			V			
8	RV	Random vehicle rule	Egbelu and Tanchoco (1984)	V						
● **Vehicle-Initiated Dispatching**										
1. Random-Based Dispatching										
1	RAN	Random assignment	Russell and Tanchoco (1984)		V					
2	RW	Random work centre	Egbelu and Tanchoco (1984)		V					
2. Distance-Based Dispatching										
1	CD	Pick-up-task-closest-to-its-destination	Bartholdi and Platzman (1989)		V		V			
2	FEFS	First encountered first served (loop)	Bartholdi and Platzman (1989)		V		V			
3	FVT	Fixed vehicle type dispatching	Lin *et al.* (2003a)		V		V			
4	LLD	Load-list dispatching	De Koster *et al.* (2004)		V		V			
5	LTT/D	Longest travel time/distance	Egbelu and Tanchoco (1984)		V		V			
6	MFVT	Mixture fixed vehicle type dispatching	Lin *et al.* (2003b)		V		V			
7	MVVT	Mix virtual vehicle type dispatching	Lin *et al.* (2004)		V		V			
8	NJF	Nearest job first	Wang and Liao (2003)		V		V			
9	NWF	Nearest-workstation-first	De Koster *et al.* (2004)		V		V			
10	POR	Preferred order by nearest load	Russell and Tanchoco (1984)		V		V			

Table 2.2 Dispatching rule summary (cont.)

No	**Rule**		**Authors**	**Workcenter -initiated**	**Vehicle-initiated**		**Distance-related**	**Time-related**	**Queue-related**	
					Source	**Demand**			**Input**	**Output**
2. Distance-Based Dispatching (cont.)										
11	SDT	Shortest distance travelled	Sabuncuoglu and Hommertzheim (1992)		V		V			
12	SR	SR-based dispatching	Sha *et al.* (2006)		V		V			
13	STD	Shortest travel time/distance	Sabuncuoglu (1998)		V		V			
14	STT/D	Shortest travel time/distance	Egbelu and Tanchoco (1984)		V		V			
15	WLD	Work-list dispatching	De Koster *et al.* (2004)		V		V			
3. Time-Based Dispatching										
1	CR	Critical ratio	Min and Yih (2003)		V			V		
2	DPI	Dispatching with pre-arrival information	De Koster *et al.* (2004)		V			V		
3	EDD	Earliest due date	Min and Yih (2003)		V			V		
4	FCFS	First come first served	Bartholdi and Platzman (1989		V			V		
5	FRFS	First request first serve	Min and Yih (2003)		V			V		
6	LIT	Longest inter-arrival time	Yim and Linnt (1993)		V			V		
7	LWKR	Least work remaining	Sabuncuoglu (1998)		V			V		
8	LWT	Longest waiting time	Russell and Tanchoco (1984)		V			V		
9	MFCFS	Modified first come first serve	Egbelu and Tanchoco (1984)		V			V		
10	SRPT	Shortest remaining process time	Min and Yih (2003)		V			V		
11	STTF	Shortest travel time first	Bozer and Yen (1996)		V			V		
12	ULSAT	Unit load shop arrival time	Egbelu and Tanchoco (1984)		V			V		
4. Hybrid Distance/Time-Based Dispatching										
1	C100FCFS	100 m/FCFS (hybrid rule)	De Koster *et al.* (2004)		V		V	V		
2	DD	Dedicated dispatching (C100FCFS)	De Koster *et al.* (2004)		V		V	V		
3	Mod FCFS	Modified first come first serve	De Koster *et al.* (2004)		V		V	V		
4	NVFTP	Nearest-vehicle-first with time priority	De Koster *et al.* (2004)		V		V	V		

Table 2.2 Dispatching rule summary (cont.)

No		Rule	Authors	Workcenter-initiated	Vehicle-initiated		Distance-related	Time-related	Queue-related	
					Source	Demand			Input	Output
5. Queue Size-Based Dispatching										
1	LNQ	Largest number in queue	Russell and Tanchoco (1984)		V					V
2	LQ	Pick-up-task-at-the-longest-queue	Bartholdi and Platzman (1989)		V					V
3	LQS	Largest queue size	Sabuncuoglu and Hommertzheim (1992)		V					V
4	LRS	Lowest remaining space in stocker	Min and Yih (2003)		V				V	
5	MOQS	Maximum outgoing queue size	Egbelu and Tanchoco (1984)		V					V
6	MRIQ	Maximum remaining incoming queue space	Yim and Linnt (1993)		V				V	
7	MROQS	Minimum remaining outgoing queue space	Egbelu and Tanchoco (1984)		V					V
6. Multi-Attribute-Based Dispatching										
1	BID	Bidding rule (α,β: simulation test)	Hwang and Kim (1998)		V		V		V	V
2	MADR	Multi-attribute decision rule (weight: neural)	Jeong and Randhawa (2001)		V		V		V	V
3	Multi-att	Multi-attribute dispatching (weight: pre-defined)	Le-Anh and De Koster (2005)		V		V	V		
4	Multi-mod	Modified multi-attribute dispatching (weight: pre-defined, p:pre-defined)	Le-Anh and De Koster (2005)		V		V	V		
7. Demand-Based (Pull) Dispatching										
1	DDA	Dynamic dispatching algorithm (levels logic checking)	Sabuncuoglu and Hommertzheim (1992)		V	V	V	V	V	V
2	DEMD	Demand driven rule (pull system)	Egbelu (1987)		V	V		V	V	V
3	MD	Maximum demand rule (JIT system)	Occena and Yokota (1991)			V	V	V	V	V
4	PP	Hybrid push/pull rule	Lin *et al.* (2006)		V	V	V		V	V

Table 2.2 Dispatching rule summary (cont.)

No	**Rule**		**Authors**	**Workcenter -initiated**	**Vehicle-initiated**		**Distance-related**	**Time-related**	**Queue-related**	
					Source	**Demand**			**Input**	**Output**
8. Reassignment-Based Dispatching										
1	B2D2	Bidding-based dynamic dispatching (current loading)	Bozer and Yen (1996)	V	V		V			
2	Combi	Combined dispatching	Le-Anh and De Koster (2005)	V	V		V	V		
3	MAM	Multi-attribute metric dispatching	Kim *et al.* (2007)		V		V	V		
4	MOD STTF	Modified shortest travel time first	Bozer and Yen (1996)	V	V		V			
5	NVF_R	Nearest vehicle first with vehicle re-assignment	Le-Anh and De Koster (2005)	V	V		V			
6	NVF_RC	Nearest vehicle first with vehicle re-assignment and cancellation	Le-Anh and De Koster (2005)	V	V		V			
9. Priority-Based Dispatching										
1	DPD	Differentiated preemptive dispatching	Wang and Liao (2004)		V		V	V		
2	NPH	Non-preemptive highest priority job first	Wang and Liao (2004)		V		V			
3	PHP	Preemptive highest priority job first	Wang and Liao (2003)		V		V			
10. Other Issues Dispatching										
(1) Multi-Lood Vehicle										
➢ **(a) Task-Determination**										
1	DTF	Delivery task first	Ho and Chien (2006)							
2	PTF	Pick up task first	Ho and Chien (2006)							
3	LR	Load ratio	Ho and Chien (2006)							
➢ **(b) Delivery-Dispatching**										
1	SD	Shortest distance	Ho and Chien (2006)	V			V			
2	SRPT	Smallest remaining processing time	Ho and Chien (2006)	V				V		
3	CM	Combination (SD+SRPT)	Ho and Chien (2006)	V			V	V		
4	SIQ	Smallest input queue	Ho and Chien (2006)	V					V	
5	LTIS	Longest time in system	Ho and Chien (2006)	V				V		

Table 2.2 Dispatching rule summary (cont.)

No	**Rule**		**Authors**	**Workcenter -initiated**	**Vehicle-initiated**		**Distance-related**	**Time-related**	**Queue-related**	
					Source	**Demand**			**Input**	**Output**
➢ **(b) Delivery-Dispatching (cont.)**										
6	LTOV	Longest time on vehicle	Ho and Chien (2006)	V				V		
7	EDT	Earliest due time	Ho and Chien (2006)	V				V		
8	LET	Longest elapsed time since last arrival	Ho and Chien (2006)	V				V		
9	SST	Smallest slack time	Ho and Chien (2006)	V				V		
10	RDM	Random	Ho and Chien (2006)	V						
➢ **(c) Pickup-Dispatching**										
1	SD	Shortest distance	Ho and Chien (2006)		V		V			
2	GOQ	Greatest output queue	Ho and Chien (2006)		V					V
➢ **(d) Load-Selection**										
1	ID	Identical-destination	Ho and Chien (2006)		V					

No	**Rule**		**Authors**	**Distance-related**	**Loading-related**	**Queue-related**	**Random**
(2) Multi-Loop / Lifter Selection							
1	FWL	Fewest number of waiting lots	Jimenez *et al.* (2002)		V		
2	RAN	Random	Jimenez *et al.* (2002)				V
3	SD	Shortest distance	Lin *et al.* (2001)	V			
4	WD	WIP travel distance	Lin *et al.* (2001)	V	V		
5	WN	WIP number	Lin *et al.* (2001)		V		
6	WR	WIP on RTM queue number	Lin *et al.* (2001)		V	V	

2.2.4 Performance Prediction

The prediction model developed for performance is required to provide guidance to practitioners in selecting a preferable setting based on the changeable environment. The delivery time forecast for both the priority lot and regular lot in the 300 mm AMHS was proposed by Liao and Wang [34]. The authors developed a neural network model trained by an OHT loop simulation model, and the lot delivery time in each loop can be estimated. Further, integer programming was used to determine the loop path with the shortest delivery time, and the total delivery time can be obtained by summarising all the delivery times in the loop-to-loop delivery path. Liang and Wang [33] decomposed the whole 300 mm AMHS into several independent loops and used the simulation to estimate the delivery time, waiting time, and blocking time of each transport loop by statistical regression. Then, the loop-to-loop delivery time can be estimated by adding all the forecast delivery times of loop along the transport path.

2.3 Production Dispatching

The production requests might not be executed immediately due to the limited resources. Thus, the dispatching is raised to check the available capability and determine the resource allocation based on the designated purpose. The mechanism of Tool Dispatching (TD) involves the determination of which wafers to process first, given that many wafers are waiting to be processed. Tyan *et al*. [57] used the TOC principles to propose the state-dependent dispatching rule specially designed for the bottleneck station. Dabbas and Fowler [12] classified the rules as local or global policies. The latter include look-behind and look-ahead, making the decision both within and outside the immediate neighborhood because of the re-entrance characteristics, leading to the requirement for dispatching to take into account the status elsewhere. Besides, the combination rules have been developed to use the mixed design to assign the optimal weight based on different criteria. In addition, some issues are focused on areas where there are particular restrictions, such as mask change, dedicated tool, and issues in full-batch. A mask is a glass plate with the circuit pattern specifically designed for a single layer. The scheduling issue attempts to minimize the mask change times to reduce the tool's set-up time; for example, the family-based rules, which group the same photo mask as a family, was proposed in Chern and Liu [11], or seeks to balance the workload between two consecutive exposure operations, like the workload-levelling (LWL) algorithm proposed in Kim *et al.* [27]. Tool dedication is due to the high-resolution operations in the critical photo layer that have to be processed by a particular high-resolution exposure tool for accurate alignment and to ensure quality. This aims to develop an algorithm to balance the workload of the dedicated tool, like the evaluation of the flexible assignment policy and dedicated assignment policy in Akcalt *et al.* [1], and the line balance (LB) dedication algorithm in Wu *et al.* [63] to smooth the flow rate based on multi-segments. Further, the full-batch process combines multiple lots with the same recipe for cleaning or oxidation deposition, and the related issue is intent upon reducing the attack on production variance due to the batch collection. Weng and Leachman [62] used the information about future arrival to develop the minimum cost rate (MCR) heuristic for reducing the variation in lead times. Kim *et al.* [27] proposed the back and front queues levelling (BFQL) rule to avoid starvation of the workstation. The algorithm used the idea of a kanban card (pull approach) under the time constraint between wet etch and furnace, as proposed in Scholl and Domaschke [53]. However, the effect of material handling was ignored in the above studies due to the simplification of the modelling.

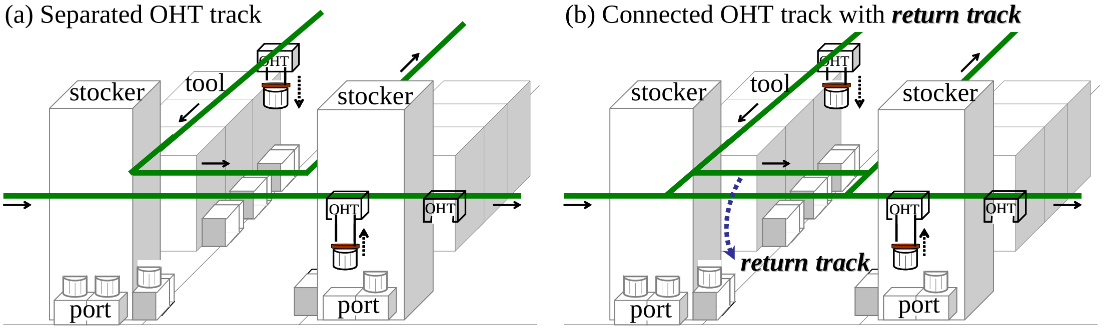
CHAPTER 3 TRANSPORT SYSTEM DESCRIPTION

3.1 Transport Facility

Generally, the 300mm AMHS is implemented as many separate loops and spreading up from a centre loop. In which the separate loops, intrabay systems take charge within bay transportation, and the centre loop, interbay system is responsible for transporting wafer between different bays. All loops are located overhead to attain zero footprints in transport and minimise the fab footprint. The wafer carrier, or front-opening unified pod (FOUP), is a kind of closed carrier with an automated door at the front side, and the vehicle, an overhead hoist transporter (OHT), is capable of carrying one FOUP at a time and has a hoisting mechanism to automatically load/unload one FOUP.

Three kinds of combination of interbay and intrabay were represented in Figure 3.1. In Figure 3.1(a), these two systems were separated loops and the tasks between different bays involved transferring by stocker. In Figure 3.1(b), these tracks were connected in front of each bay, and the return track made the within-bay transport more efficient. In Figure 3.1(c), the tracks were connected in front of each bay by turntable, but this turntable is a kind of resource restriction, because there might be some vehicles waiting for a turntable to move to interbay or intrabay, or even wait for a straight move in interbay or return to intrabay. Hence, traffic congestion occurs.

Under above combination layouts, not only can the wafer be delivered without labour for transport loading, but also that the mishandling, particle contamination and vibration shocks to the wafers can be reduced. Especially in Figure 3.1(b) and (c), FOUP can be delivered directly tool-to-tool without transferring by stocker and so decreasing delivery variation. In this research, the configuration of Figure 3.1(b) is the object of study, and the simplified layout of the object system is displayed in Figure 1.1.


(a) Separated OHT track

(b) Connected OHT track with ***return track***

(c) Connected OHT track with ***turn table***

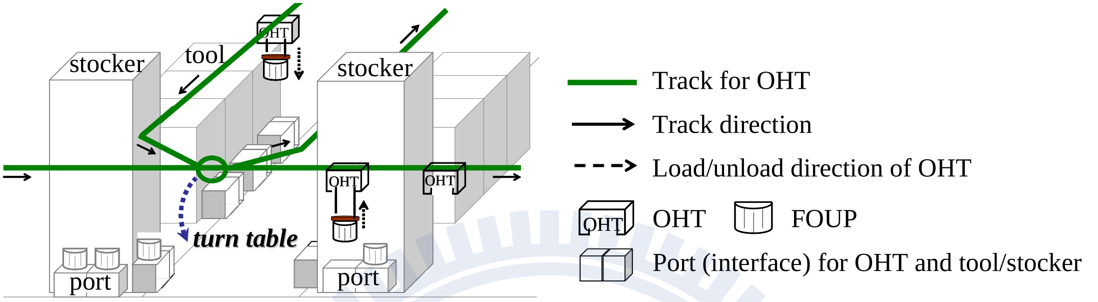


Figure 3.1 Configurations of the 300mm AMHS

The interface for vehicle to input and retrieve FOUP through stocker in the Figure 3.1(b) configuration is displayed in Figure 3.2. It shows that the transport can be flexibly operated for handling different transport requirement. For instance, vehicle *A* will unload one FOUP to stocker *A*. It can travel on interbay track to unload that FOUP on port *b*, or go through intrabay track to unload on port *c*. The terminal port and travel path are determined based on the transport strategy.

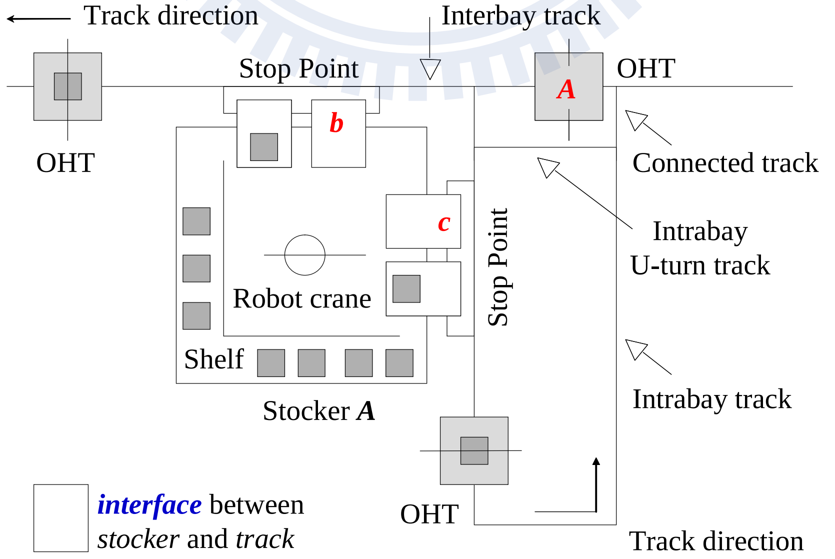


Figure 3.2 Interface of OHT and stocker

3.2 Transport Operation

The four types of the tool-to-tool transport operation between different bays utilising different facilities are shown in Figure 3.3. The suffix number in OHT refers to the vehicle used in transporting. Which type of operation would be used is determined based on the transport strategy. The more times to transfer FOUP through stocker, the more time are required to complete the tool-to-tool transport. And also, all types, except type 4, involve another complex stocker selection issue. However, alothought the type 4 transport needs not transfer the FOUP by stocker; the directly tool-to-tool transport requires detecting the status of both source and destination tools and the transport will be happened while destination tool requests/pulls the next one FOUP to process from source tool when it just becomes idle, which likes the JIT (Just in Time) concept. In this research, only type 4 will be considered in Search Range (SR) assignment issue, while type 3 and type 4 are considered in Integrated Dispatching (ID) issue for focusing the studies.

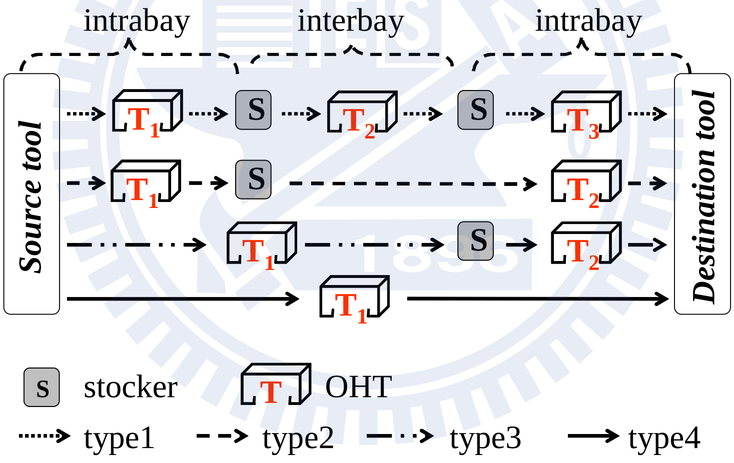


Figure 3.3 Types of the tool-to-tool transport operation

3.3 Dispatching Operation

The dispatching is raised to check the available capability and to determine the resource allocation based on the designated rule. Moreover, Tool Dispatching (TD) involves the determination of which FOUP should be process first, given that many FOUPs are waiting to be processed. Vehicle Dispatching (VD) involves the determination of which FOUP to transport first, given that many FOUPs are waiting to be moved. The authors classified the dispatching into five categories, as the FOUP-searches/selects-tool (FST), the FOUP-searches/selects-stocker (FSS), the tool- searches/selects-FOUP (TSF), the FOUP- searches/selects-vehicle (FSV), and the vehicle-searches/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.

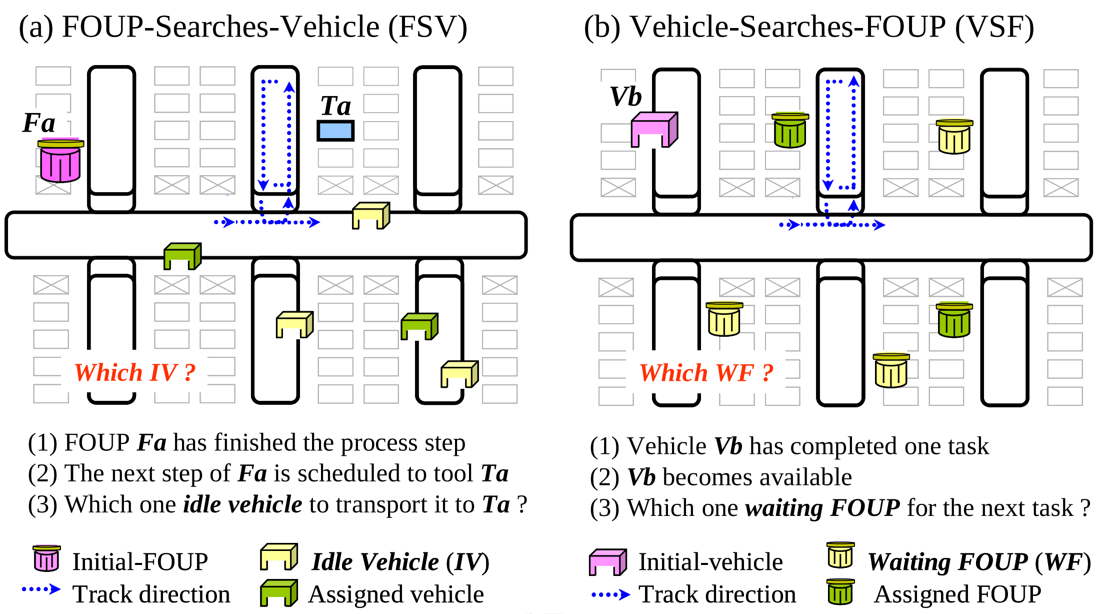
(3) TSF deals with the selection of a specific FOUP from a set of waiting FOUP as a tool's next task.

(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 dispatching operations in this study are foused on FSV and VSF, in which FSV resembles work-centre-initiated task assignment and VSF resembles vehicle-initiated task assignment in Egbelu and Tanchoco [16]. The descriptions please see Figure 3.4.

Some definitions of VD are: (1) *FSV successfully* means that when FSV occurs, the FOUP finds an appropriate *IV* and assigns it to transport. On the contrary is *FSV unsuccessfully*; (2) *VSF successfully* means when VSF occurs, the vehicle finds an appropriate *WF* and assigns it for the next task. On the contrary is *VSF unsuccessfully*. Furthermore, the statuses of vehicles include: (1) idle, which has no FOUP to transport and waits for assignment; (2) empty, which has assigned by a FOUP and just moves to pick up that FOUP; (3) loaded, which has assigned by a FOUP and is executing the transport now.


(a) FOUP-Searches-Vehicle (FSV)

(b) Vehicle-Searches-FOUP (VSF)

(1) FOUP ***Fa*** has finished the process step
(2) The next step of ***Fa*** is scheduled to tool ***Ta***
(3) Which one ***idle vehicle*** to transport it to ***Ta*** ?

(1) Vehicle ***Vb*** has completed one task
(2) ***Vb*** becomes available
(3) Which one ***waiting FOUP*** for the next task ?

Figure 3.4 Definition of vehicle dispatching operations

3.4 System Problem Descrition

In the literatures, the range of search to find the FOUP or vehicle for service is only in the one loop where the transport request initial, like Figure 3.5(a), (b) and (c). What the range of search when dispatching occurs in the environment likes Figure 3.5 (d) is the first issue required to treatment.

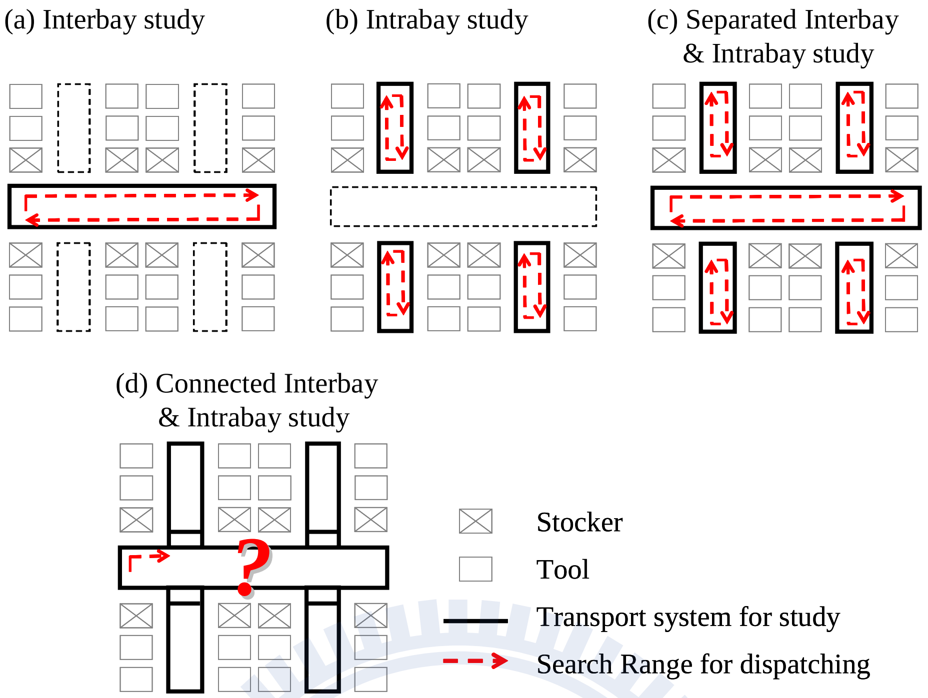


Figure 3.5 Range of search in vehicle dispatching studies

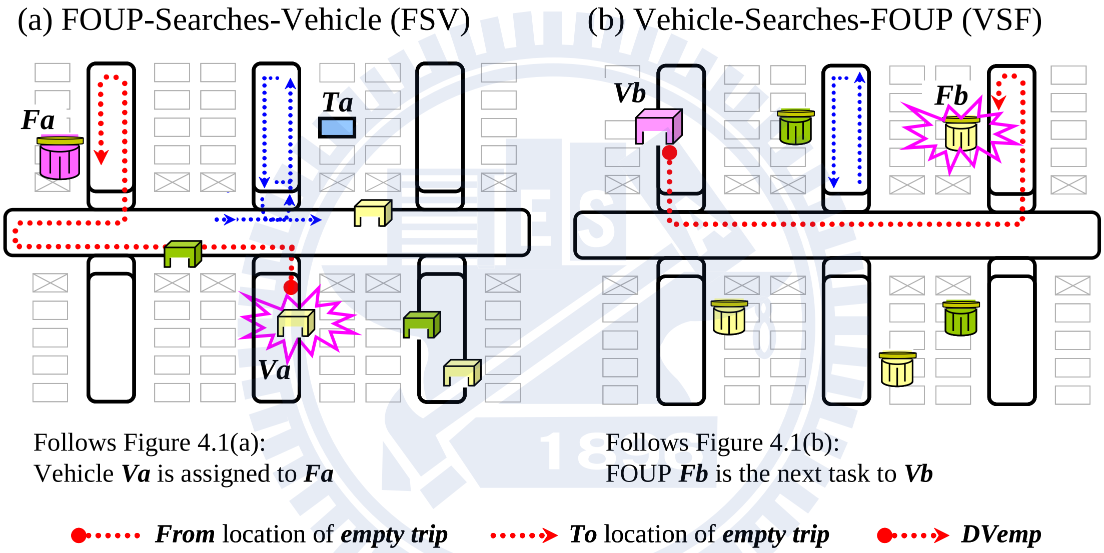
Further, as the close interactions between production and transport in the fully-auto manufacturing environment, the functions of transport are not only to give service to the production requests, like moving FOUP to its downstream tool, but should carry out some *activities* to smooth the production for fully-supporting. Thus, it is necessary to identify the interactions between TD and VD, and to develop a transport strategy that will evaluate a tool’s capability and then adjust the FOUP’s transport priority when executing VD for better vehicle allocation.

The dispatching behavior and boundry considered in above two problems are shown in Figure 1.3, and the details please see the following sections.

CHAPTER 4 SEARCH RANGE (SR) ASSIGNMENT

4.1 Problem Definition

The dispatching rules used in this study are a combination of the nearest vehicle (NV) for FSV and the shortest travel distance (STD) for VSF, which were addressed in Egbelu and Tanchoco [16]. The bases of these distance-related rules are to minimize the distance vehicle travel empty, which is relevant to the characteristic of the problem described in the following. In addition, the distance of a vehicle's empty trip is defined as *DVemp*, which means the distance which the vehicle travels to the location of the FOUP without load, by which the vehicle is assigned. Please see Figure 4.1.


(a) FOUP-Searches-Vehicle (FSV)

(b) Vehicle-Searches-FOUP (VSF)

Follows Figure 4.1(a):
Vehicle ***Va*** is assigned to ***Fa***

Follows Figure 4.1(b):
FOUP ***Fb*** is the next task to ***Vb***

Figure 4.1 Definition of vehicle's empty trip

The utility time of a vehicle consists of above three elements' time: idle time, empty time and loaded time. The *idle time* is related to the system loading, and the higher loading is, the idle time might be shorter. The *empty time* is adjustible to reductions depending on dispatching decisions, and is considered a key element in increasing the transport time. Figure 4.2 explains the shortened length of empty time, the transport time of FOUP can be reduced. Hence, to reduce the *DVemp* is a method to reduce vehicle's empty time and than provide the service to others transport requirement. The *loaded time* is based on the transport time of a FOUP from the current process tool to its downstream tool.

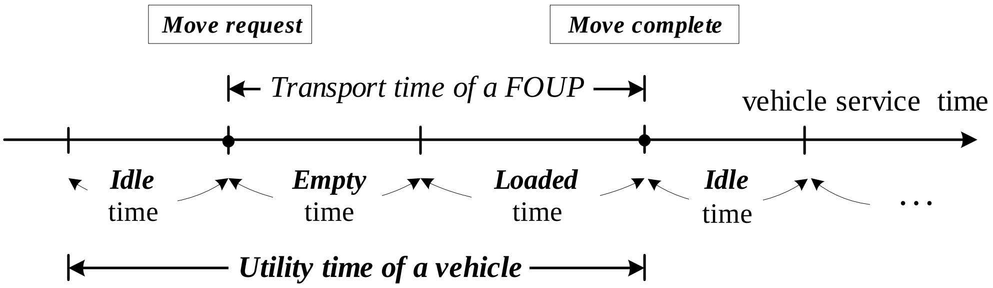


Figure 4.2 Utility time of a vehicle

When a vehicle completes a task and triggers VSF to search a waiting FOUP (defined as *WF*) for the next task, the SR of VSF is used to "determine how far the *WFs* from that vehicle will be considered for transport, and then indirectly limit the *DVemp* between that vehicle and the assigned *WF*" while dispatching successfully. If the SR is set too narrow, the vehicle might find no *WF* in the range, while there are actually many waiting to be transported. In addition, if the SR is set too wide and the vehicle assigns a farther *WF* successfully, the empty trip of that vehicle will be increased a significant distance from its location.

The other situation is when a FOUP completes the process step and triggers FSV to search an idle vehicle (defined as *IV*) to transport it to the next process tool or destination. The SR of FSV is used to "determine how far the *IVs* from that FOUP will be considered for transport, and then indirectly limit the *DVemp*" too. The range for search, whether too narrow or wide, will not only increase the time of FOUP to wait for being assigned or wait for vehicle to pick it up, but also affect vehicle utilisation and traffic conditions. For this reason, an applicable SR for dispatching is required to make vehicle work effectively.

4.2 Two-Phase Approach for SR Assignment

A two-phase approach with simulation is used to develop SR. Phase I is to collect the transport records for analysizing the trend and distribution of *DVemp* while Phase II is to design levels of SR based on the phase I result, and then evaluate which level is practicable. The architecture of approach is displayed in Figure 4. 3, and the details please see the following sections.

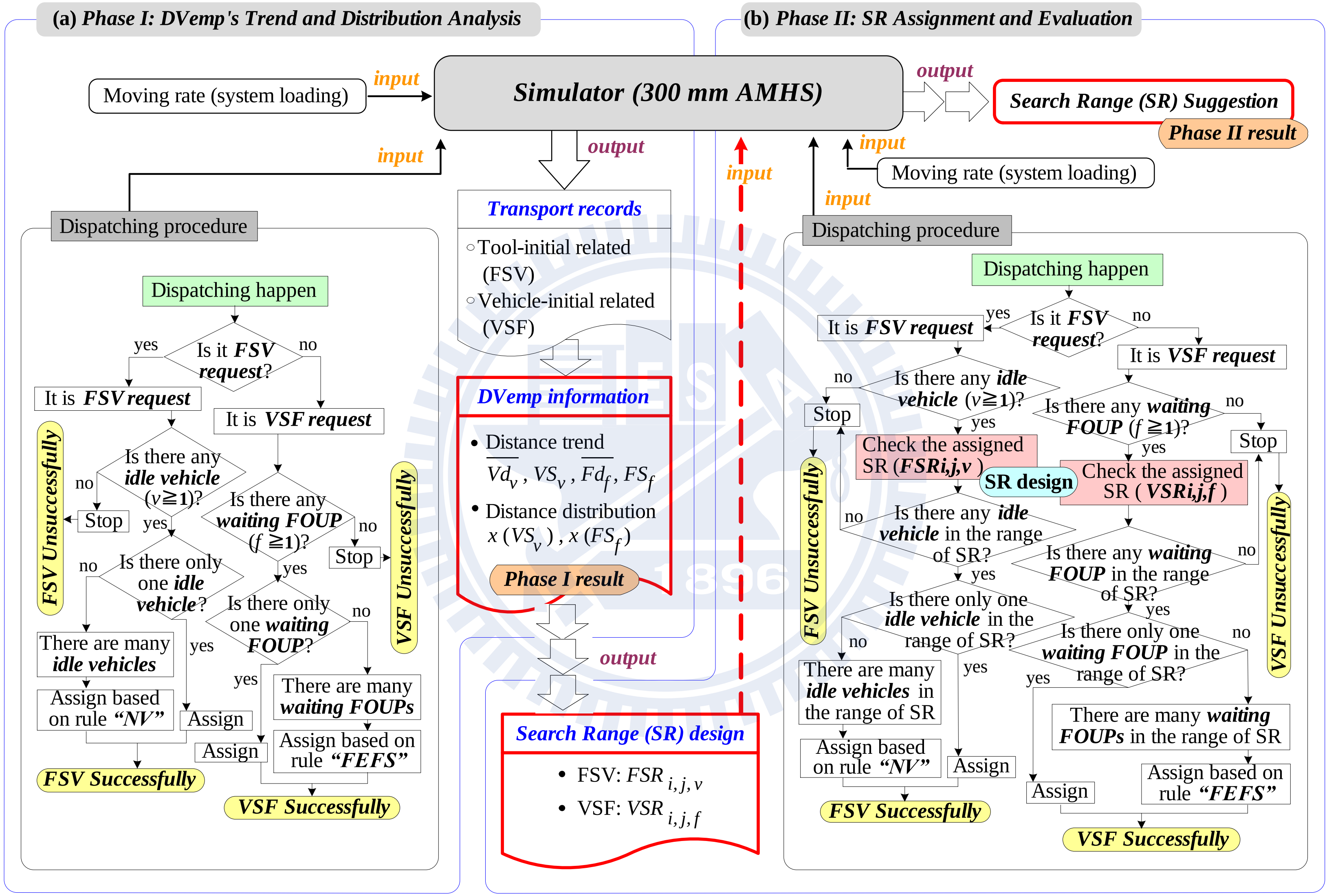


Figure 4. 3 Architecture of two-phase approach

4.2.1 Phase I: *DVemp*'s Trend and Distribution Analysis

Some factors might affect the *DVemp* such as dispatching rules, vehicle travel path and so forth. In this phase, the effect of "the number of *IVs* and *WFs* at the time when dispatching occurs" is the focus.

A. Records Collection

The records needed to collect include: (a) the number of *IVs* and "*DVemp* between FOUP and the assigned *IV*" when FSV successfully; (b) the number of *WFs* and "*DVemp* between vehicle and the assigned *WF*" when VSF successfully. The notations to define the records are listed as follows.

(1) FOUP and vehicle related:

(a) *F*: FOUP, which initials a FSV request.

(b) *WF*: waiting FOUP, which waits for a vehicle to assign.

(c) *V*: vehicle, which initials a VSF request.

(d) *IV*: idle vehicle, which waits for an FOUP to assign.

(2) FSV related:

(a) v: the number of *IV* when FSV occurs. $v = 1, 2, \ldots, n_1$; n_1 is the number of vehicle required which is pre-calculated for model.

(b) k_v: the accumulated number of FSV requests under v. $k_v = 1, 2, \ldots, k$; $1 \leq v \leq n_1$.

(c) $d_{x,v,kv}(F,IV)$: the *DVemp* between *F* and assigned *IV* under the x^{th} *IV*, v and k_v. $x = 1, 2, \ldots, v$; $1 \leq v \leq n_1$; $k_v = 1, 2, \ldots, k$.

(d) $Vd_{v,kv} = Min\ [d_{x,v,kv}(F,IV)]$. $x = 1, 2, \ldots, v$; $1 \leq v \leq n_1$; $k_v = 1, 2, \ldots, k$.

(e) $\overline{Vd}_v$: the average distance of $Vd_{v,kv}$. $1 \leq v \leq n_1$; $k_v = 1, 2, \ldots, k$.

(f) VS_v: the standard variation of $Vd_{v,kv}$. $1 \leq v \leq n_1$; $k_v = 1, 2, \ldots, k$.

(3) VSF related:

(a) f: the number of *WF* when VSF occurs. $f = 1, 2, \ldots, n_2$; n_2 is the biggest number of *WF* in system during the simulation time period, and n_2 would be larger if system loading is higher.

(b) m_f: the accumulated number of VSF under f. $m_f = 1, 2, \ldots, m$; $1 \leq f \leq n_2$.

(c) $d_{y,f,mf}$ *(V,WF)*: the *DVemp* between *V* and assigned *WF* under the y^{th} *WF*, *f* and m_f. $y = 1, 2, \ldots, f$; $1 \le f \le n_2$; $m_f = 1, 2, \ldots, m$.

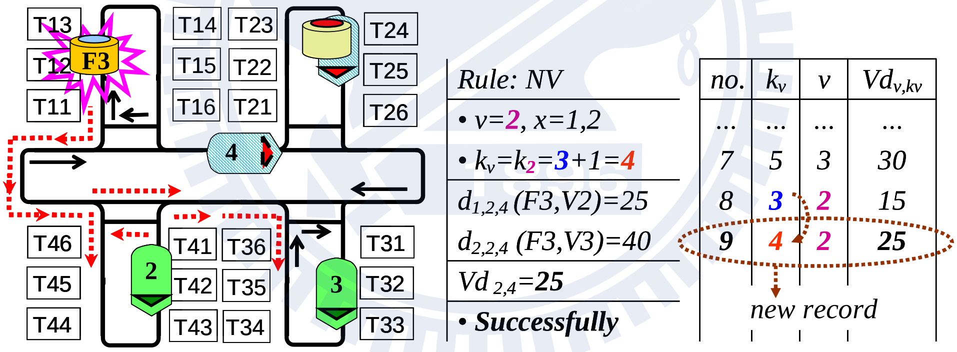
(d) $Fd_{f,mf} = Min\ [d_{y,f,mf}\ (V,WF)]$. $y = 1, 2, \ldots, f$; $1 \le f \le n_2$; $m_f = 1, 2, \ldots, m$.

(e) $\overline{Fd}_f$: the average value of $Fd_{f,mf}$. $1 \le f \le n_2$; $m_f = 1, 2, \ldots, m$.

(f) FS_f : the standard variation of $Fd_{f,mf}$. $1 \le f \le n_2$; $m_f = 1, 2, \ldots, m$.

It has to notice that when $v = 0$ or $f = 0$, which was FSV or VSF unsuccessfully, no information needs to be recorded. The following examples illustrate how to collect records. In Figure 4.4, *F3* in T12 triggered a FSV request and the number of records have been collected already is 8 (*no.*=8). In Figure 4.4(a), there are 2 *IVs*, which are V2 and V3 (v=2; x=1, 2); the Figure 4.4(b) is the case of v=3 and x=1, 2, 3. If FSV occurs and there is no *IV* (v=0), then FSV unsuccessfully, as shown in Figure 4.4(c). In the other situation, if the vehicle triggered a VSF request to search the next transport task, the search direction is opposite to the direction of FSV.

(a) FSV (v=2)



Rule: NV

- $v=\mathbf{2}$, $x=1,2$
- $k_v=k_2=\mathbf{3}+1=\mathbf{4}$

$d_{1,2,4}$ (F3,V2)=25

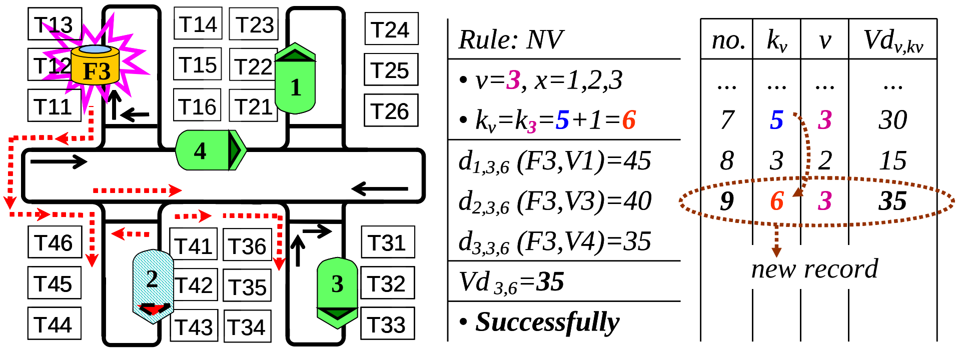
$d_{2,2,4}$ (F3,V3)=40

$Vd_{2,4}$=**25**

- ***Successfully***

no.	k_v	v	$Vd_{v,kv}$
…	…	…	…
7	5	3	30
8	3	2	15
9	4	2	**25**

(b) FSV (v=3)



Rule: NV

- $v=\mathbf{3}$, $x=1,2,3$
- $k_v=k_3=\mathbf{5}+1=\mathbf{6}$

$d_{1,3,6}$ (F3,V1)=45

$d_{2,3,6}$ (F3,V3)=40

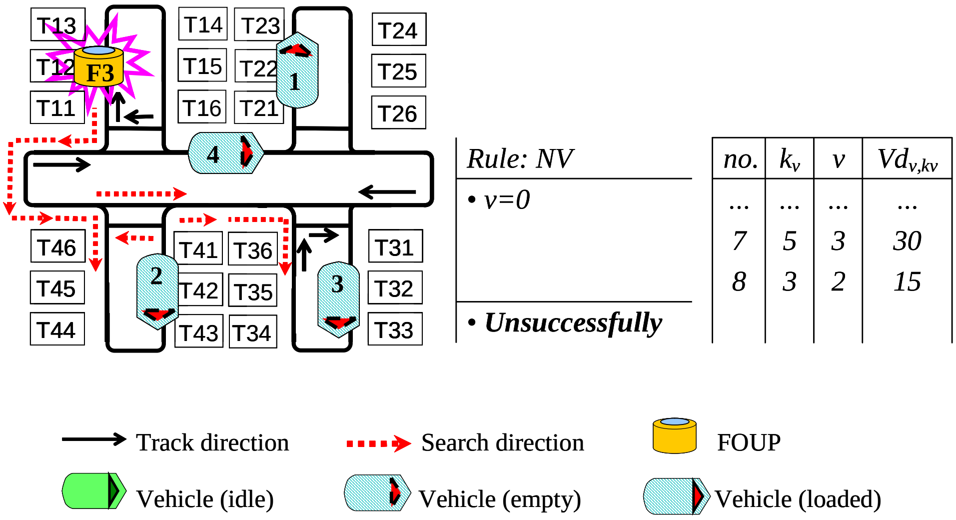
$d_{3,3,6}$ (F3,V4)=35

$Vd_{3,6}$=**35**

- ***Successfully***

no.	k_v	v	$Vd_{v,kv}$
…	…	…	…
7	5	3	30
8	3	2	15
9	6	3	**35**

(c) FSV (v=0)



no.	k_v	v	$Vd_{v,kv}$
...	...	...	...
7	5	3	30
8	3	2	15

Figure 4.4 Example of transport records collection

B. Distance Trend

Once the transport records were collected, the following data can be obtained.

(a) $\overline{Vd}_v$: the average distance of $Vd_{v,kv}$. $1 \le v \le n_1$; $k_v = 1, 2, ..., k$.

(b) VS_v : the standard variation of $Vd_{v,kv}$. $1 \le v \le n_1$; $k_v = 1, 2, ..., k$.

(c) $\overline{Fd}_f$: the average value of $Fd_{f,mf}$. $1 \le f \le n_2$; $m_f = 1, 2, ..., m$.

(d) FS_f : the standard variation of $Fd_{f,mf}$. $1 \le f \le n_2$; $m_f = 1, 2, ..., m$.

Further, the average and standard deviation of *DVemp* under different numbers of *IV* (v) and *WF* (f), which are (1) $\overline{Vd}_v$ and VS_v under v, $v = 1, 2, \ldots, n_1$ and (2) $\overline{Fd}_f$ and FS_f under f, $f = 1, 2, \ldots, n_2$ can be summarised for trend observed. When FSV occurs under different v or when VSF occurs under different f must lead to different distance required for vehicle to pick up the assigned FOUP. This distance required implies that dispatching will be successfully when the *IV* is *"in the distance"* far from the *F* or the *WF* is *"in the distance"* far from the *V*. This result states that SR might set as practicable distance required under different v and f.

C. Distance Distribution

To observe the *DVemp*'s distribution, the distance intervals of *DVemp* were recorded and the percentages of the accumulated number of each interval were calculated based on the following rules. If the *DVemp* satisfied following distance interval, then record the distribution with "$x\sigma$". Some notations were described as follows.

(1) The rules to define the distance interval

- (a) FSV records
  - (i) If $\overline{Vd}_v + (x\text{-}0.5)^* VS_v \leqq DVemp < \overline{Vd}_v + x^* VS_v$;

    $x = 0.5, 1, 1.5, 2, 2.5, 3.$
  - (ii) If $\overline{Vd}_v + x^* VS_v \leqq DVemp < \overline{Vd}_v + (x+0.5)^* VS_v$;

    $x = -3, -2.5, -2, -1.5, -1, -0.5.$
- (b) VSF records
  - (i) If $\overline{Fd}_f + (x\text{-}0.5)^* FS_f \leqq DVemp < \overline{Fd}_f + x^* FS_f$;

    $x = 0.5, 1, 1.5, 2, 2.5, 3;$
  - (ii) If $\overline{Fd}_f + x^* FS_f \leqq DVemp < \overline{Fd}_f + (x+0.5)^* FS_f$;

    $x = -3, -2.5, -2, -1.5, -1, -0.5.$

(2) Percentage of the accumulate distribution in distance interval

(a) $k_{x\sigma}\% =$

$$\left(\frac{\text{the accumulate number of FSV's } \textit{DVemp} \text{ fell in the distance interval "x}\sigma\text{"}}{\text{the total number of FSV request}}\right) * 100\%$$

(b) $m_{x\sigma}\% =$

$$\left(\frac{\text{the accumulate number of VSF's } \textit{DVemp} \text{ fell in the distance interval "x}\sigma\text{"}}{\text{the total number of VSF request}}\right) * 100\%$$

The distance distribution of $k_{x\sigma}\%$ and $m_{x\sigma}\%$ under FSV and VSF might bring us an idea that if SR set under a given distance interval, the expected percentage of dispatching will be successfully. Hence, under which distance interval will make the performance perform better can further be evaluated. According to the empirical rule of normal distribution in probability statistics, the normal density curves satisfy the property that 68.26%, 95.44% and 99.74% of the observations fall within 1, 2 and 3 standard deviations of the mean respectively. Thus, for a normal distribution, almost all values lie within 3 standard deviations of the mean.

Consequently, the *DVemp*'s trend and distribution inspired to develop SR. The main idea is to assign SR under different v and f, and the range of search should be set no longer than 3σ ($3*VS_v$, $3*FS_f$) of $\overline{Vd}_v$ or $\overline{Fd}_f$.

4.2.2 Phase II: SR Assignment and Evaluation

The SR is developed for different v and f under the different system loading, and separated into two parts, FOUP-initiated SR (FSR) and vehicle-initiated SR (VSR). Developing the levels of SR (SR_j) is based on records from phase I and designed as the average distance of *DVemp* ($\overline{Vd}_v, \overline{Fd}_f$), plus the multiple ($j$) of *DVemp*'s standard deviation (VS_v, FS_f). The SR is defined as follows.

(1) $FSR_{i,j,v}$: the SR of FSV (FSR) under MR_i and SR_j when IV number is v.

$$FSR_{i,j,v} = \begin{cases} \overline{Vd}_v + (j * VS_v) \quad (m) \quad if \;\; j > 0 \\ the\ total\ track\ length\ in\ fab \quad (m) \quad if \;\; j = 0 \end{cases}$$

(2) $VSR_{i,j,f}$: the SR of VSF (VSR) under MR_i and SR_j when WF number is f.

$$VSR_{i,j,f} = \begin{cases} \overline{Fd}_f + (j * FS_f) \quad (m) \quad if \;\; j > 0 \\ the\ total\ track\ length\ in\ fab \quad (m) \quad if \;\; j = 0 \end{cases}$$

where $j = 0$ (SR_0: $FSR_{i,0,v}$, $VSR_{i,0,f}$) represents the current way operated in the object real fab which is the total length of tracks around the fab. It indicates that all the *WF* or *IV* will be considered for dispatching no matter how long the *DVemp* the vehicle has to travel. The purpose to set SR_0 is to set as the baseline model and to test if SR is required in dispatching. Otherwise, $j > 0$, implies the limited *DVemp*. The moving rate (MR) MR_i, indicates as transport amount is designed to vary the system loadings i (see Section 4.3.2). Further, the SR will be evaluated through the following simulation experiment.

4.3 Simulation Modeling

The performance of SR assignment was evaluated by a discrete event simulation model built using the object-oriented simulation software eM-Plant^{TM} [17], and the data was analyzed using statistics software Design-Expert^{TM} [56].

4.3.1 Capacity Facilitated

The simplified layout is a reference from Lin *et al.* [38], which portrays a 300mm wafer fab from Taiwan, R.O.C. There are a total of 123 tools and the AMHS includes one interbay and eight intrabay systems, as depicted in Figure 4.5. Zone control is used to prevent traffic collision (Garry [19]).

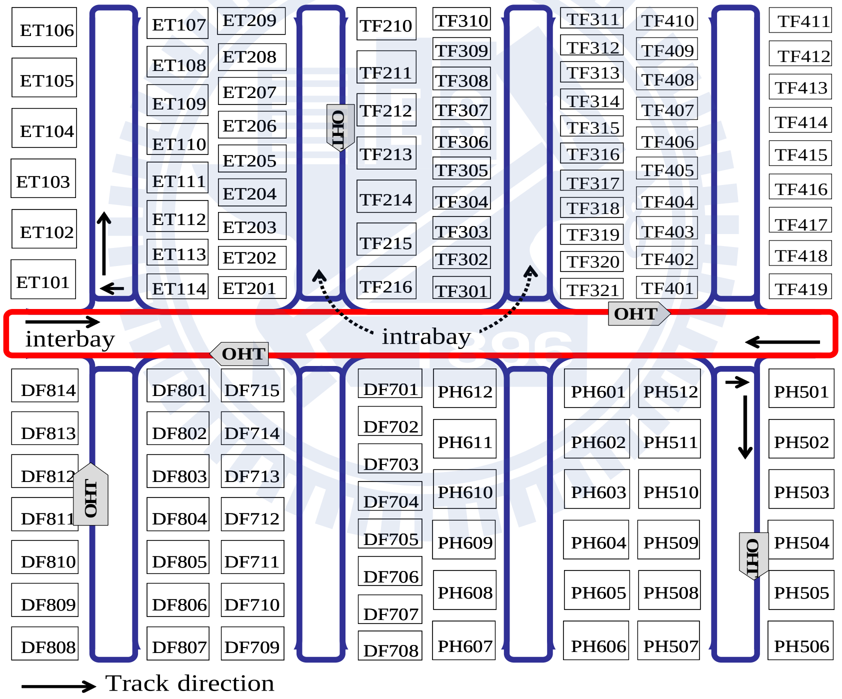


Figure 4.5 Simplified layout of a 300 mm wafer fab

4.3.2 Transport Information

The transport information includes (1) from–to distance; (2) from–to quantity; (3) system average moving rate (MR) per hour, which is the average arrival rate of all the tools; and (4) inter-arrival time of each tool, which is the average time interval of transport task requests from tools and follows exponential distribution. These data were calculated from the moving records in the manufacturing execution system (MES) over two months. Some examples are shown in Table 4.1 and Table 4.2.

Table 4.1 Examples of tools' average inter-arrival time

MR (lots/hr)	Tools									
	ET101	ET102	ET103	ET104	ET105	ET106	ET107	ET108	ET109	ET110
70	1:02:10	1:02:10	1:02:10	1:02:10	26:08	35:02	3:38:00	3:38:00	3:38:00	4:23:49
105	41:26	41:26	41:26	41:26	17:25	23:21	2:25:20	2:25:20	2:25:20	2:55:52
140	31:05	31:05	31:05	31:05	13:04	17:31	1:49	1:49	1:49	2:11

Note: (a) The time is the mean of exponential distribution. (b) Time format is hh: mm: ss.

Table 4.2 Examples of from-to moving quantity

From (Tools)	To (Tools)								
	ET201	ET202	ET203	ET204	ET205	ET206	ET207	ET208	…
ET201	0	4	4	5.5	5.5	39.5	39.5	39.5	
ET202	5	0	14.5	0.25	0.25	0.63	0.63	0.63	
ET203	5	14.5	0	0.25	0.25	0.63	0.63	0.63	
ET204	15	0	0	0	35	0.5	0.5	0.5	
ET205	15	0	0	27	0	0.5	0.5	0.5	
ET206	25.5	0.5	0.5	0.75	0.75	0	40	40	
…									

4.3.3 Model Assumption

The following assumptions are made to facilitate the simulation model:

(1) Four ports of each tool.
(2) Inter-arrival time of tools is an exponential distribution (examples see Table 4.1).
(3) Acceleration and deceleration of vehicle are ignored.
(4) Breakdown and battery recharge of vehicle are not considered.
(5) Idle vehicle (wait for request) travels in interbay system.

4.3.4 Vehicle Number Required

The number of vehicles required is an important factor, as it indicates the transport capability. Egbelu [15] introduced the concept of expected value to estimate the number of empty runs, and then calculated the initial number of AGV required by performing empty and loaded runs. The exact formulas are:

(1) The number of empty runs from station i to station j is given by g_{ij}.

$$g_{ij} = \frac{(Expected\ no.\ of\ \ deliveries\ to\ i)\times(Expected\ no.\ of\ \ pickups\ \ from\ \ j)}{Expected\ total\ \ no.\ of\ \ pickups\ throughout\ the\ system}$$

$$= \left[\left(\sum_{k=1}^{n} f_{ki}\right) * \left(\sum_{k=1}^{n} f_{jk}\right)\right] \Big/ \left(\sum_{i=1}^{n}\sum_{j=1}^{n} f_{ij}\right)$$

where n is number of stations in the facility; f_{ij} is expected number of loaded trips required between station i and station j during the period.

(2) The total distance traveled from station i to station j is given by Dij.

$$D_{ij} = D'_{ij} + \overline{D_{ij}} = \left[\ g_{ij} * d\left(\alpha_i, \beta_j\right)\right] + \left(\ f_{ij} * d\left(\beta_i, \alpha_j\right)\right)$$

where D'_{ij} is empty runs distance; $\overline{D_{ij}}$ is loaded runs distances; α_i is node label corresponding to the delivery station i, i =1, 2, …, n; β_j is node label corresponding to the pickup station j, j =1, 2, …, n; $d(\beta_i, \alpha_j)$ is distance between node β_i and node α_j.

(3) The number of vehicles required is calculated according to

$$N = \left[\left(\sum_{i=1}^{n}\sum_{j=1}^{n} D_{ij} / V\right) + \left(\sum_{i=1}^{n}\sum_{j=1}^{n} f_{ij}\right)(t_u + t_t)\right] \Big/ \left(60T - t\right)$$

where T is length of the period during which the f_{ij} exchanges occur (hours); V is average vehicle travel speed; t_u is mean time to unload a vehicle; t_t is mean time to load a vehicle; t is mean expected lost time by each vehicle during a time period of T due to battery change.

In this study, n = 123; T is two months which is 86,400 minutes; V = 1m/sec; $t_u = t_t$ = 20 sec; t = 0. From the formulae and the moving data described above, we can obtain N (vehicle's initial number) = 4.18; however the number was underestimated because the formulae did not estimate the time increase caused by traffic problems like congestion, nor the vehicles' idle time. Therefore, experiments to evaluate what the multiples of N to set as vehicle number in the model were performed. The experiment evaluated four levels of multiples, as 1.5, 2, 2.5 and 3 for N with the simulation model described above. The indices are described in Section 4.4.1, except vehicle empty utilisation was replaced by vehicle utilisation to be fully utilised. The bigger the vehicle utilisation, the better. The experiment condictions are described in Section 4.4.2.

The result shown in Table 4.3 showed that the fewer number of vehicles leads to higher vehicle utilization but longer time-related indices; gaining the shorter time-related indices needed more vehicles but lower vehicle utilization. Hence the multiple response method to integrate multiple indices into one is used. For the analysis procedure, please refer to Section 4.4.3 *B*. The result showed that if the vehicle number is $\lfloor N \times 2\,(multiples\,) \rfloor$= 9, it would make the system stable and the indices performed better than other multiples. Hence the vehicle number was set as 9 for the following experiments.

Table 4.3 Experiment result of vehicle number required

MR (lots/hr)	Sequence	multiples	TP (lots)	stdDT (sec)	WT (sec)	Vutil (%)	Desirability	
70	***1***	***2***	***45965.8***	***40.8***	***34.2***	***36.3***	***0.616***	***Selected***
	2	2.5	45946.0	37.8	27.3	28.9	0.527	
	3	3	45988.7	36.5	31.7	24.1	0.197	
	4	1.5	45959.3	51.1	45.7	49.2	0.187	
105	***1***	***2***	***68948.8***	***53.2***	***41.6***	***57.7***	***0.614***	***Selected***
	2	2.5	68737.0	42.0	28.8	44.6	0.296	
	3	3	68911.3	38.7	22.4	36.8	0.216	
	4	1.5	68998.3	94.4	76.4	79.7	0.128	
140	***1***	***2***	***91824.9***	***86.7***	***65.6***	***81.5***	***0.626***	***Selected***
	2	2.5	91644.7	53.9	37.5	62.6	0.495	
	3	3	91687.3	43.3	27.2	50.5	0.179	
	4	1.5	91745.0	243.7	177.5	97.9	0.111	

4.4 Simulation Experiment

4.4.1. Performance Indices

The performance indices are outlined as follows for evaluating the proposed transport strategy under the simulation conditions described in Section 4.3.

(1) Throughput (TP, lots): the total quantity of transport tasks completed;

(2) Waiting time (WT, sec): the time that FOUP waits for a vehicle to assign, not including the time of the vehicle’s empty trip to pick it up;

(3) Standard deviation of delivery time (stdDT, sec): standard deviation of delivery time, which is the time from FOUP requests to move to when that FOUP is loaded on the destination by vehicle;

(4) Vehicle empty utilisation (Vemp, %): the utilisation of vehicle for empty trips.

The standard deviation of delivery time is used to obtain expected and stable status, where a smaller number is better. The lower the vehicle empty utilisation is, the better. These indices are not only used to evaluate the performance, but also to verify whether or not the system is stable under different scenarios. If the indices show that the system is unstable under certain scenarios – in other words these scenarios are not practicable – they will be deleted and not considered in the follow-up analysis.

4.4.2. Phase I Experiment

A. Experiment Design

The transport records under different system loading are collected, in which the system loading is defined as *vehicle's loading rate* in this research. Three levels of system loading MR as MR_i, $i = 1$, 2, 3, where MR_1, MR_2, MR_3 is 70 lots/hr, 105 lots/hr, 140 lots/hr respectively indicates the vehicle's transport amount per hour, and the *vehicle's loading rate* corresponds to these three levels of MR is 36%, 58%, 82% respectively (shown in Table 4.3). The higher the MR means the higher the transport requirements, and then brings the higher *vehicle's loading rate* under the fixed vehicle number environment (N=9).

This experiment was performed by one factor, MR, with three levels. The dispatching procedure is shown in Figure 4. 3(a), and four indices are measured to verify whether or not the system is stable.

B. Experiment Results and Discussion

From the indices measured by simulation, the residual analysis of these data satisfied the model assumptions (normality, independence of error term, constant variance) (Montgomery [45]) and there is no significant difference between the replications at each level of moving rate (MR). The transport records from one replication were picked out randomly, and the average and standard deviation of *DVemp* under different numbers of *WF* (*f*) and *IV* (*v*) were summarised for observing the *DVemp*'s trend (Figure 4.6). Some discussions are as follows.

(1) The *more IV* was, the *shorter* $\overline{Vd}_v$ and VS_v when FSV occurs. See Figure 4.6 (a), (c), (e); the *more WF* was, the *shorter* $\overline{Fd}_f$ and FS_f when VSF occurs. See Figure 4.6(b), (d), (f).

(2) *F* or *V* may find and assign the *nearer IV* or *WF* and make the *shorter DVemp* if there are *more IV*s or *WFs*; *F* or *V* may find and assign the *farther IV* or *WF* and make the *longer DVemp* if there are *fewer IVs* and *WFs*.

(3) The number of *IV* and *WF* at the time when dispatching occurs will affect the *DVemp*.

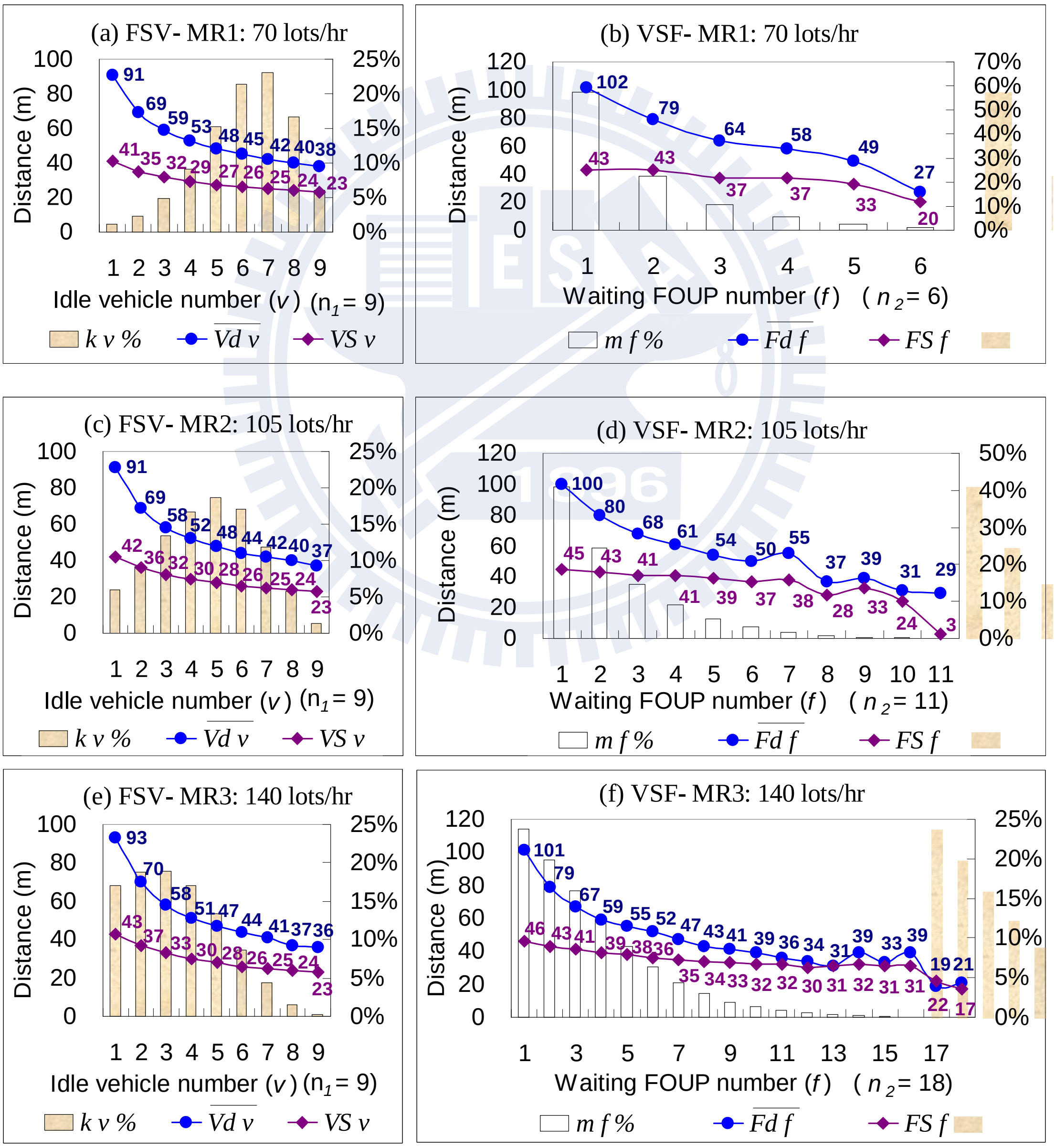


Figure 4.6 *DVemp*’s trend

Furthermore, the *DVemp*'s distribution displayed in Figure 4.7 show that the *DVemp*'s distribution gathered between the intervals from -2.5σ to 3σ and almost all the *DVemp* of transport records felled into these intervals.

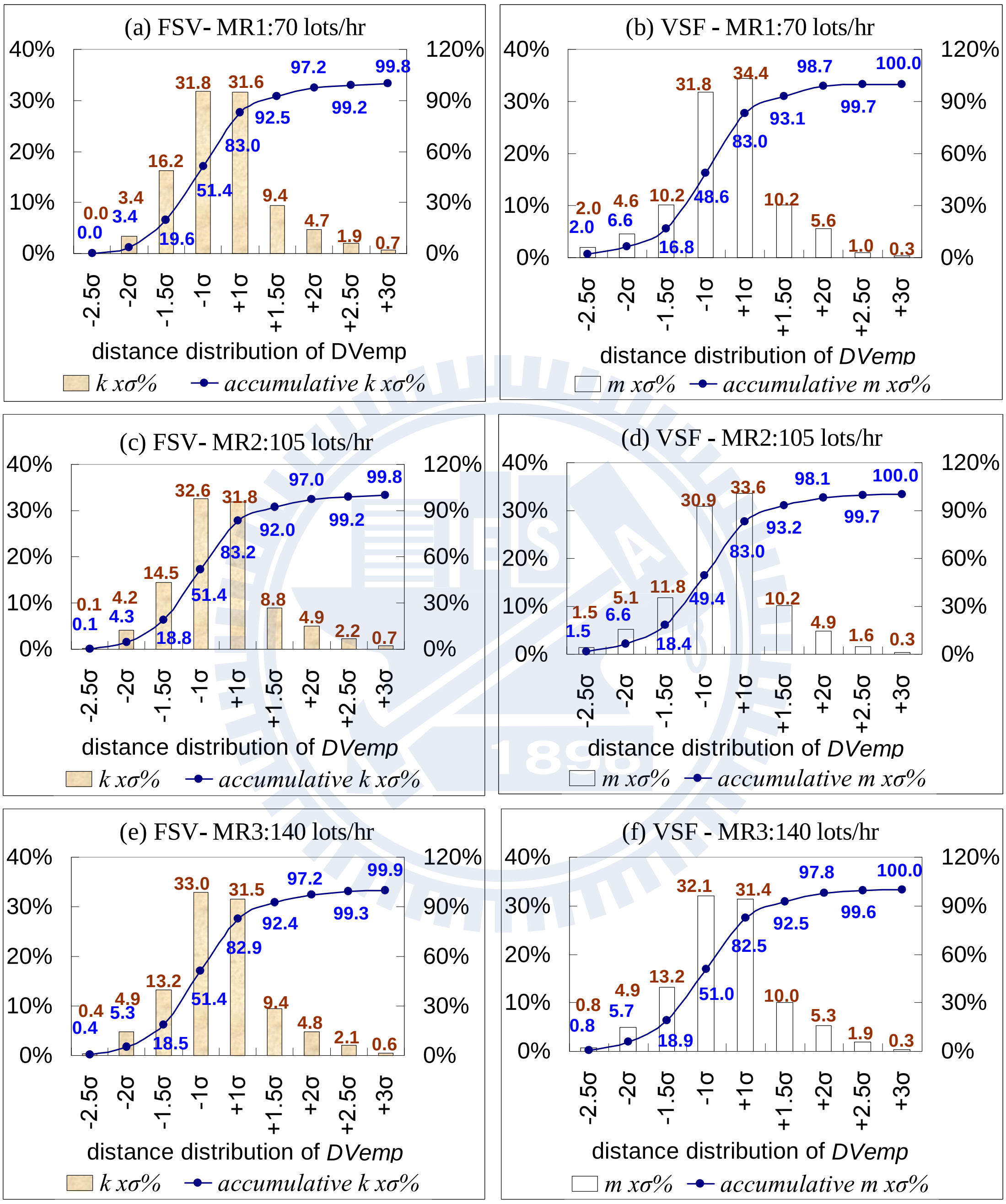


Figure 4.7 *DVemp*'s distribution

Consequently, the *DVemp*'s trend and distribution inspired to develop the SR assignment. The main idea is that *more WFs* or *IVs* in the system made the *shorter DVemp*, so *shorter* SR is adequate. Otherwise, *fewer IVs* or *WFs* in the system made the *longer DVemp*, so a *longer* SR is required and has a higher chance to dispatch successfully. Hence we will design an appropriate SR under a different number of *IV* (*v*) and *WF* (*f*), and the SR should be set no longer than 3σ of $\overline{Vd_v}$ or $\overline{Fd_f}$.

4.4.3. Phase II Experiment

A. Experiment Design

Two factors are designed to evaluate the appropriate SR under a different number of *IV* (*v*) and *WF* (*f*), and only the *WFs* or *IVs* in the assigned range will be considered when dispatching occurs. The dispatching procedure is shown in Figure 4. 3(b). The factors and levels selected were as follows.

(a) Factor A: Moving Rate (MR); numeric factor, three levels. Levels of MR were MR_i, i = 1, 2, 3, where MR_1, MR_2, MR_3 is 70 lots/hr, 105 lots/hr, 140 lots/hr respectively.

(b) Factor B: Search Range (SR); categorical factor, six levels. Levels of SR were SR_j, j = 1, 1.5, 2, 2.5, 3, 0. The SR definition was made as follows, and the levels of SR are shown in Table 4. 4

(1) $FSR_{i,j,v}$: the SR of FSV under MR_i and SR_j when *IV* number is *v*.

$$FSR_{i,j,v} = \begin{cases} \overline{Vd_v} + (j * VS_V) \quad (m) \quad if \ \ j = 1, 1.5, 2, 2.5, 3 \\ 608.50 \quad (m) \quad if \ \ j = 0 \end{cases}$$

(2) $VSR_{i,j,f}$: the SR of VSF under MR_i and SR_j when *WF* number is *f*.

$$VSR_{i,j,f} = \begin{cases} \overline{Fd_f} + (j * FS_f) \quad (m) \quad if \ \ j = 1, 1.5, 2, 2.5, 3 \\ 608.50 \quad (m) \quad if \ \ j = 0 \end{cases}$$

Where v = 1, 2, …, n_1; n_1 = 9; f = 1, 2, …, n_2; n_2 = 6, 11, 18 at i = 1, 2, 3 respectively (see Figure 4.6).

Table 4. 4 Levels of SR assignment

$FSR_{i,j,v}(m)$																					
v	*i*=1							*i*=2							*i*=3						
	j							*j*							*j*						
	0.5	*1*	*1.5*	*2*	*2.5*	*3*	*0*	*0.5*	*1*	*1.5*	*2*	*2.5*	*3*	*0*	*0.5*	*1*	*1.5*	*2*	*2.5*	*3*	*0*
1	111	131	152	172	193	213	608.5	111	132	152	173	194	214	608.5	114	135	156	177	198	219	608.5
2	86	104	121	138	155	173	608.5	86	104	121	139	156	174	608.5	87	105	123	142	160	178	608.5
3	74	90	105	121	136	152	608.5	74	90	105	121	137	153	608.5	74	90	106	122	138	154	608.5
4	67	82	96	111	125	139	608.5	67	81	96	111	126	140	608.5	65	80	95	109	124	138	608.5
5	61	75	88	102	115	129	608.5	61	74	88	101	115	129	608.5	61	74	88	102	115	129	608.5
6	57	70	83	95	108	121	608.5	56	69	82	95	107	120	608.5	56	69	82	95	108	120	608.5
7	54	66	78	90	102	114	608.5	53	66	78	90	102	114	608.5	52	65	77	89	101	113	608.5
8	52	63	75	87	98	110	608.5	51	62	74	86	97	109	608.5	49	61	73	84	96	108	608.5
9	49	60	71	83	94	105	608.5	47	58	69	80	92	103	608.5	47	58	69	80	91	102	608.5

$VSR_{i,j,f}(m)$																					
f	*i*=1							*i*=2							*i*=3						
	j							*j*							*j*						
	0.5	*1*	*1.5*	*2*	*2.5*	*3*	*0*	*0.5*	*1*	*1.5*	*2*	*2.5*	*3*	*0*	*0.5*	*1*	*1.5*	*2*	*2.5*	*3*	*0*
1	123	144	165	186	207	228	608.5	122	145	167	189	212	234	608.5	124	146	169	192	215	238	608.5
2	99	120	141	163	184	205	608.5	100	121	143	164	185	206	608.5	100	122	144	165	187	209	608.5
3	81	99	117	136	154	172	608.5	87	108	128	148	168	188	608.5	87	108	128	149	169	190	608.5
4	76	94	113	131	149	167	608.5	81	101	121	141	161	181	608.5	79	99	118	138	157	176	608.5
5	65	81	97	113	130	146	608.5	73	92	112	131	151	170	608.5	74	93	112	132	151	170	608.5
6	36	46	56	66	76	86	608.5	68	86	105	123	141	159	608.5	70	88	106	125	143	161	608.5
7								73	91	110	129	147	166	608.5	64	82	99	117	134	151	608.5
8								50	64	78	92	106	119	608.5	60	77	94	111	128	145	608.5
9								55	71	87	104	120	136	608.5	57	74	91	107	124	141	608.5
10								42	54	65	77	89	101	608.5	55	71	87	103	120	136	608.5
11								30	32	33	34	36	37	608.5	52	69	85	101	117	133	608.5
12															49	64	79	94	109	124	608.5
13															47	62	78	94	109	125	608.5
14															55	71	87	103	120	136	608.5
15															49	64	79	95	110	126	608.5
16															55	70	86	101	117	132	608.5
17															29	40	51	62	73	84	608.5
18															29	38	46	55	63	71	608.5

A traditional statistical experimental design with two-factor full-factorial (Montgomery [45]) was used. The number of scenarios was 3(MR)*6(SR) = 18, and the number of experiments performed was 18(combination)*10(replications) = 180. The simulation interval was 30 days, and warm-up was 2 days.

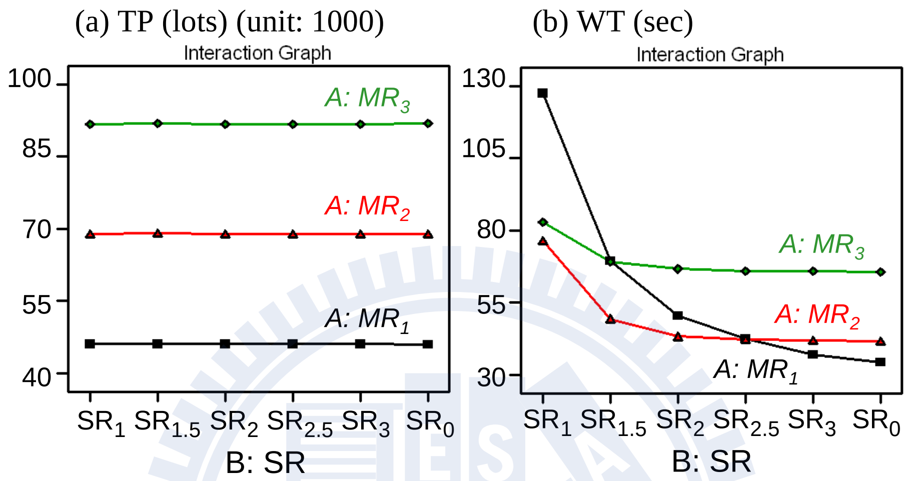
B. Experiment Result and Discussion

The ANOVA analysis as summarised in Table 4.5 indicates that the MR significantly affects all indices. Also, the SR and the interaction significantly affect all indices except the TP at 95% confidence level. The response trend under levels of MR and SR can be observed from the interaction graphs, as depicted in Figure 4.8.

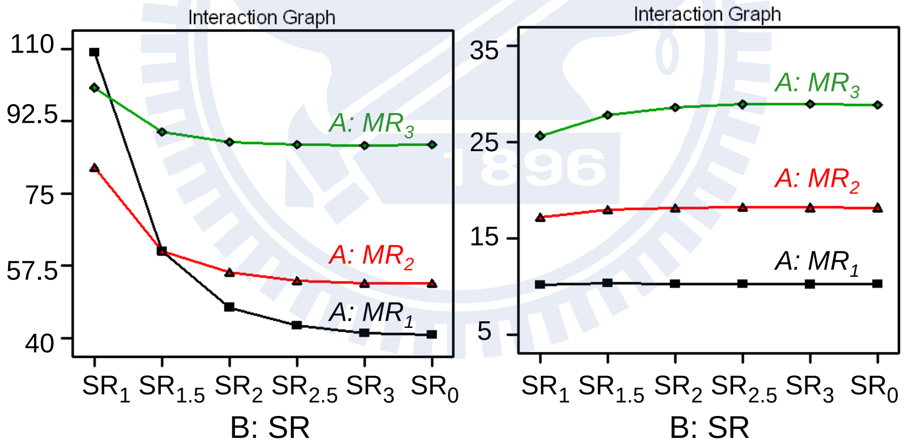
Table 4.5 P-values in SR phase II experiment

Indices	Factors				R^2
	MR	SR	MR^2	MR*SR	
TP (lots)	< 0.0001*	0.4611	0.0122*	0.2997	0.9999
WT (sec)	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*	0.9715
stdDT (sec)	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*	0.9825
Vemp (%)	< 0.0001*	< 0.0001*	< 0.0001*	< 0.0001*	0.9996

*=significant at 95% confidence level


(a) TP (lots) (unit: 1000)

(b) WT (sec)


(c) stdDT (sec)

(d) Vemp (%)

Figure 4.8 The Interaction graphs of MR and SR

Further, the Post Hoc Multiple Comparisons was done with the least significant difference (LSD) method to compare all pairs of the six SR under each of the three MR, as summarised in Table 4.6. The value is the mean of performance, measured from the 10 replications, and the rank in the different alphabet means the effects of SR were significant at 95% confidence level. Table 4.6 implied that the shorter SR made for a longer WT because the narrow range decreased the chance for the vehicle to find the *WFs*, and then the *WFs* need more time to wait for being assigned; the

Vemp would be lower (better) and indicates vehicle work more efficiently while SR is shorter. However, no SR outperforms the others in all indices.

Table 4.6 Post Hoc Multiple Comparisons in SR phase II experiment

MR (lots/hr)	SR	Indices							
		TP (lots)		WT (sec)		stdDT (sec)		Vemp (%)	
		rank	mean	rank	mean	rank	mean	rank	mean
70	SR_1	A	46016.6	F	126.461	E	110.121	A	10.141
	$SR_{1.5}$	A	46016.5	E	69.673	D	60.955	C	10.296
	SR_2	A	46016.8	D	50.376	C	47.398	BC	10.251
	$SR_{2.5}$	A	46016.7	C	42.346	B	43.070	AB	10.216
	SR_3	A	46016.4	B	36.860	A	41.220	AB	10.196
	SR_0	A	45965.8	A	34.192	A	40.803	AB	10.203
105	SR_1	A	68946.5	D	76.295	D	81.238	A	17.167
	$SR_{1.5}$	A	69011.8	C	49.328	C	60.999	B	17.951
	SR_2	A	68946.9	B	43.230	B	55.840	C	18.116
	$SR_{2.5}$	A	68947.1	A	42.111	A	53.778	D	18.195
	SR_3	A	68946.7	A	41.930	A	53.278	D	18.182
	SR_0	A	68948.8	A	41.565	A	53.178	CD	18.173
140	SR_1	A	91687.7	C	82.731	C	100.732	A	25.629
	$SR_{1.5}$	A	91890.4	B	69.161	B	89.929	B	27.789
	SR_2	A	91687.9	A	66.607	A	87.376	C	28.579
	$SR_{2.5}$	A	91688.5	A	65.974	A	86.772	D	28.849
	SR_3	A	91687.6	A	65.944	A	86.638	D	28.886
	SR_0	A	91824.9	A	65.611	A	86.744	D	28.866

Therefore, a multiple response method called desirability (Myers & Montgomery, Stat Ease) [46, 56] is used to integrate multiple indices into one. The method makes use of an objective function *D(X)*, called the desirability function.

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

where *n* is the number of responses; *di* is the desirable range for each response, $0 \leqq di \leqq 1$; and D(*X*) is a geometric mean of all transformed responses. The desirability of SR_j under MR_i is shown in Figure 4.9, and some discussions are as follows.

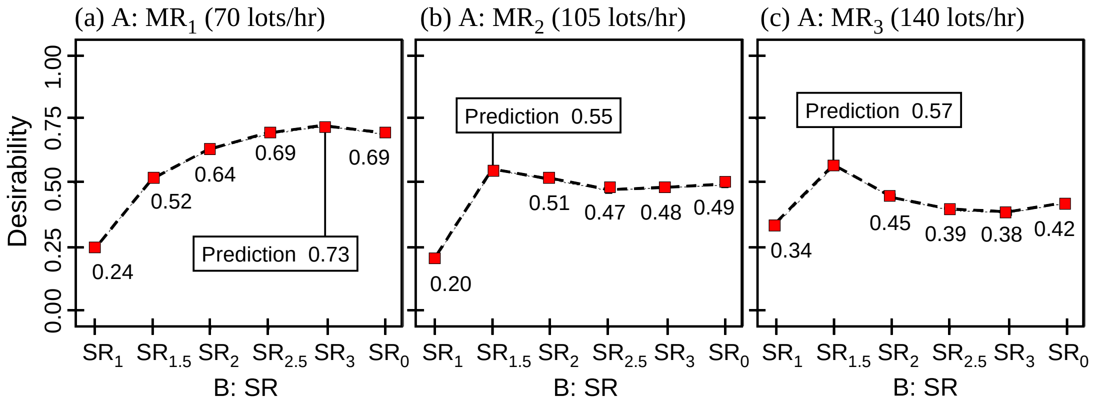


Figure 4.9 The desirability of SR for each MR

(1) SR_1 is not applicable in any system loading. Too narrow a range decreases the chance for dispatching successfully, and then makes more WT and higher stdDT for FOUP, even if it can enable lower Vemp; see Figure 4.9 and Table 4.6.

(2) In a light system (fewer *WFs*) such as MR_1, a shorter SR is not appropriate. Responses to the phase I result in fewer *WFs* making a longer *DVemp*. Hence a longer SR such as $SR_{2.5}$ or SR_3 or SR_0 makes for better performance; see Figure 4.9(a).

(3) In a heavy system (more *WFs*) such as MR_2 and MR_3, the longer SR is not required. Responses to the phase I result in more *WFs* making a shorter *DVemp*. Hence a shorter SR such as $SR_{1.5}$ makes for better performance; see Figure 4.9(b), (c).

(4) The *WFs* or *IVs* far from *V* or *F* could be ignored by setting an appropriate SR. For instance, ignoring 7.5% (4.8% + 2.1% + 0.6%) *IVs* for FSV and 7.5% (5.3% + 1.9% + 0.3%) *WFs* for VSF, of which the *DVemp* is longer than the interval +1.5σ under MR_3 to improve performance; see Figure 4.7(e), (f) and Figure 4.9(c).

(5) The result of testing if SR is required also can be seen. SR_0 might be used in a light system such as MR_1 because of its simpler control logic and performance is close to the optimal SR_3; see Figure 4.9(a). However, if system loading is increasing to MR_2 or MR_3, SR_0 is not applicable; see Figure 4.9(b), (c).

Finally, the model equations in terms of coded factors (because there is a category factor) can be used to predict the response at a interesting point, where code for factor A: MR is -1, 0, 1 at MR_1, MR_2, MR_3 respectively, and B[1], B[2],…, B[5] is to represent factor B: SR as SR_1, $SR_{1.5}$,…, SR_3

respectively. The code for factor B: SR is 0 or 1. The model equations also can provide guidance for practitioners in selecting the preferable setting based on the changeable environment and performance measures.

(1) TP (lot) =

$$68958.0 + 22868.2*A - 19.9*B[1] + 69.4*B[2] - 19.7*B[3] - 19.4*B[4] - 20.0*B[5] - 81.6*A^2 - 32.6*AB[1] + 68.8*AB[2] - 32.6*AB[3] - 32.3*AB[4] - 32.6*AB[5]$$

(2) WT (sec) =

$$49.1 + 4.7*A + 35.7*B[1] + 3.3*B[2] - 6.1*B[3] - 9.3*B[4] - 11.2*B[5] + 15.6*A^2 - 26.5*AB[1] - 4.9*AB[2] + 3.4*AB[3] + 7.1*AB[4] + 9.9*AB[5]$$

(3) stdDT (sec) =

$$59.7 + 16.2*A + 28.5*B[1] + 1.7*B[2] - 5.4*B[3] - 7.7*B[4] - 8.5*B[5] + 13.8*A^2 - 20.9*AB[1] - 1.7*AB[2] + 3.8*AB[3] + 5.6*AB[4] + 6.5*AB[5]$$

(4) Vemp (%) =

$$17.96\% + 8.94\%*A - 1.12\%*B[1] - 0.08\%*B[2] + 0.22\%*B[3] + 0.33\%*B[4] + 0.33\%*B[5] + 1.19\%*A^2 - 1.20\%*AB[1] - 0.20\%*AB[2] + 0.22\%*AB[3] + 0.38\%*AB[4] + 0.40\%*AB[5]$$

CHAPTER 5 TRANSPORT STRATEGIES IN INTEGRATED DISPATCHING (ID)

5.1 Problem Definition

The dispatching procedure of the object fab shown in Figure 5.1 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 (Egbelu [14]). 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 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 Vehicle Dispatching (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 Tool Dispatching (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.

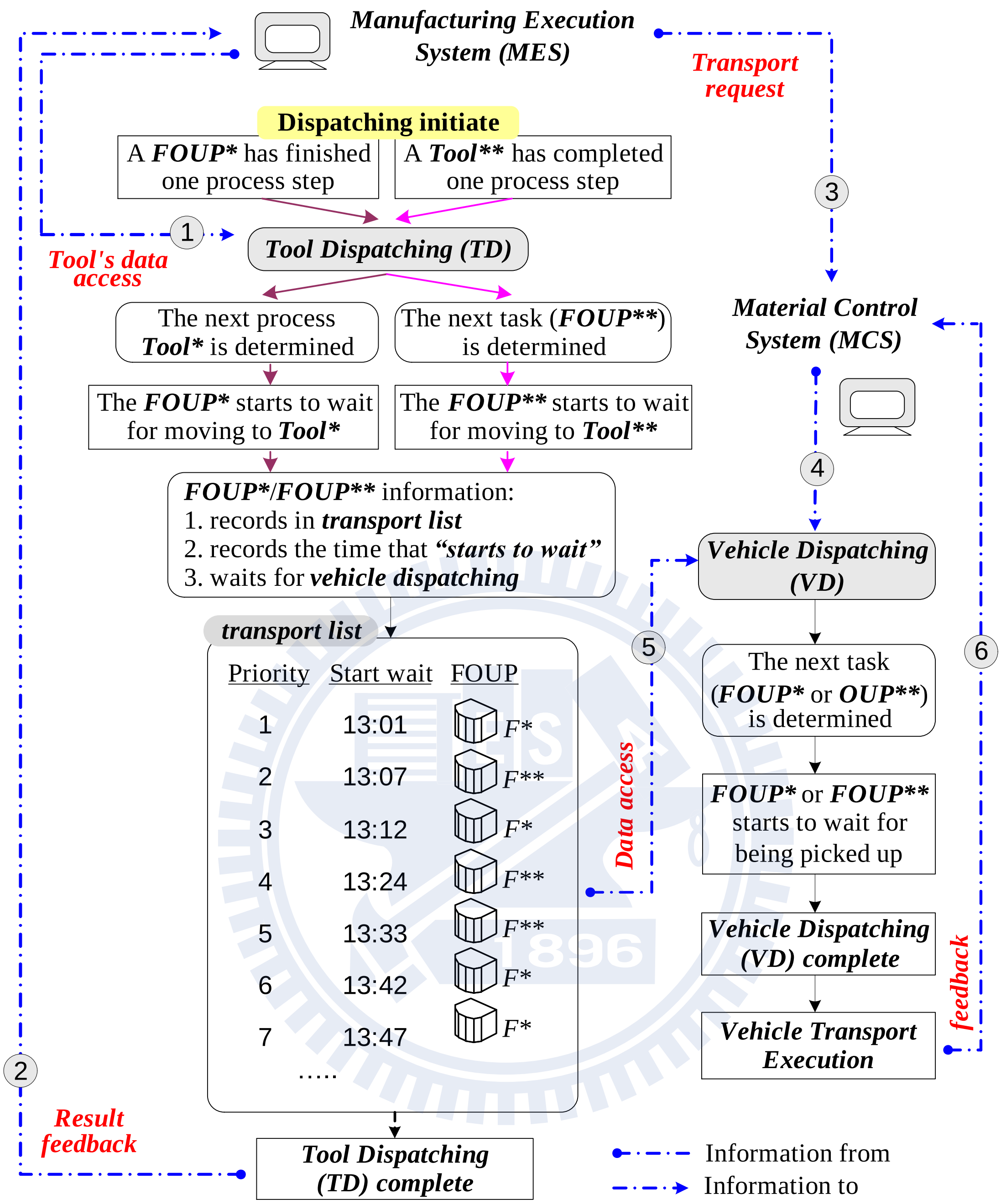


Figure 5.1 Dispatching decision-making procedure

5.2 Transport Strategy

The current VD is based on the attribute of FOUP which is to select *the longest waiting time* first and then determine the destination, either the tool or stocker. This operation can be therefore described as *source driven* dispatching in Egbelu [14]. The transport strategy the author proposed considers the demand states of the tool first, like blocking, starving or batch process, and then selects the appropriate FOUP for that tool. This is described as *demand driven* dispatching in Egbelu [14]. Hence, the *demand driven* transport is proposed in the Integrated Dispatching (ID) in this research.

5.2.1 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 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 $nPa \in \{0,1, \ldots, nP\}$, $nPr \in \{0,1, \ldots, nP\}$, $nPp \in \{0,1\}$, $nPn \in \{0,1, .., nP\text{-}1\}$, $nPo \in \{0,1, \ldots, nP\}$. 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 5.2, 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* 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.

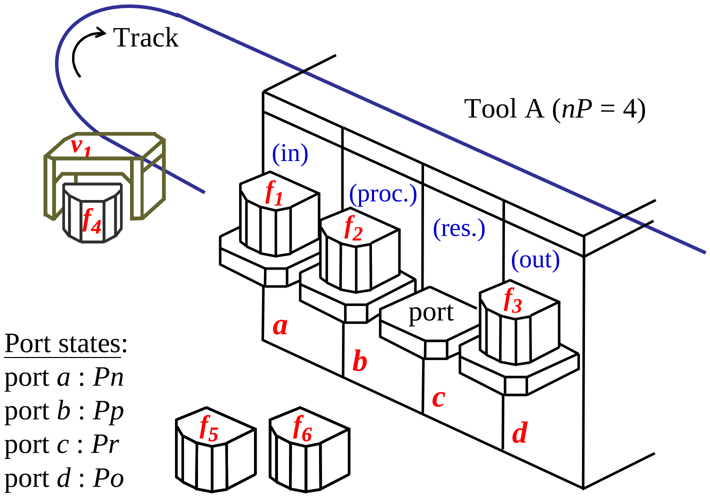


Figure 5.2 States of a tool's port

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.

5.2.2 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.

5.2.3 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. Due 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 5.3 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.

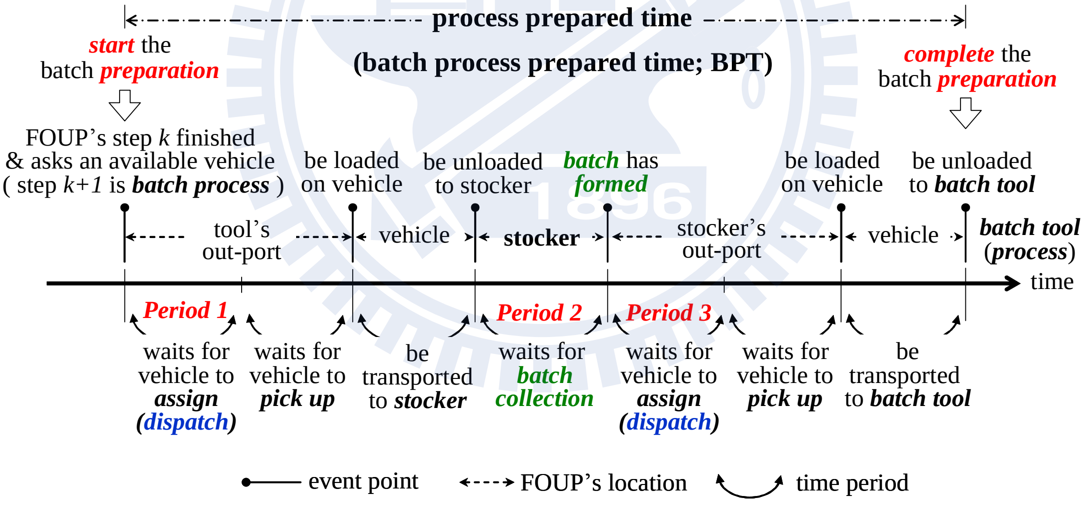


Figure 5.3 Time composing of batch process preparation

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 due to the tool being idle for batch preparation can be reduced.

5.3 Tool and Vehicle Dispatching Integrated (TVDI) Architecture

5.3.1. Decision-making Procedures

A five-level decision-making procedure is implemented in the Tool and Vehicle Dispatching Integrated (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 FOUPs which have "special property" will be selected as candidates for transport in this level.

Accordingly, the five dispatching operations 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) described in Section 3.3 are defined in the *candidate selection*. FST, FSS**,** and TSF belong to TD, while FSV and VSF are parts of VD. 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 5.4, and in which the third and fourth levels are listed in Table 5.1.

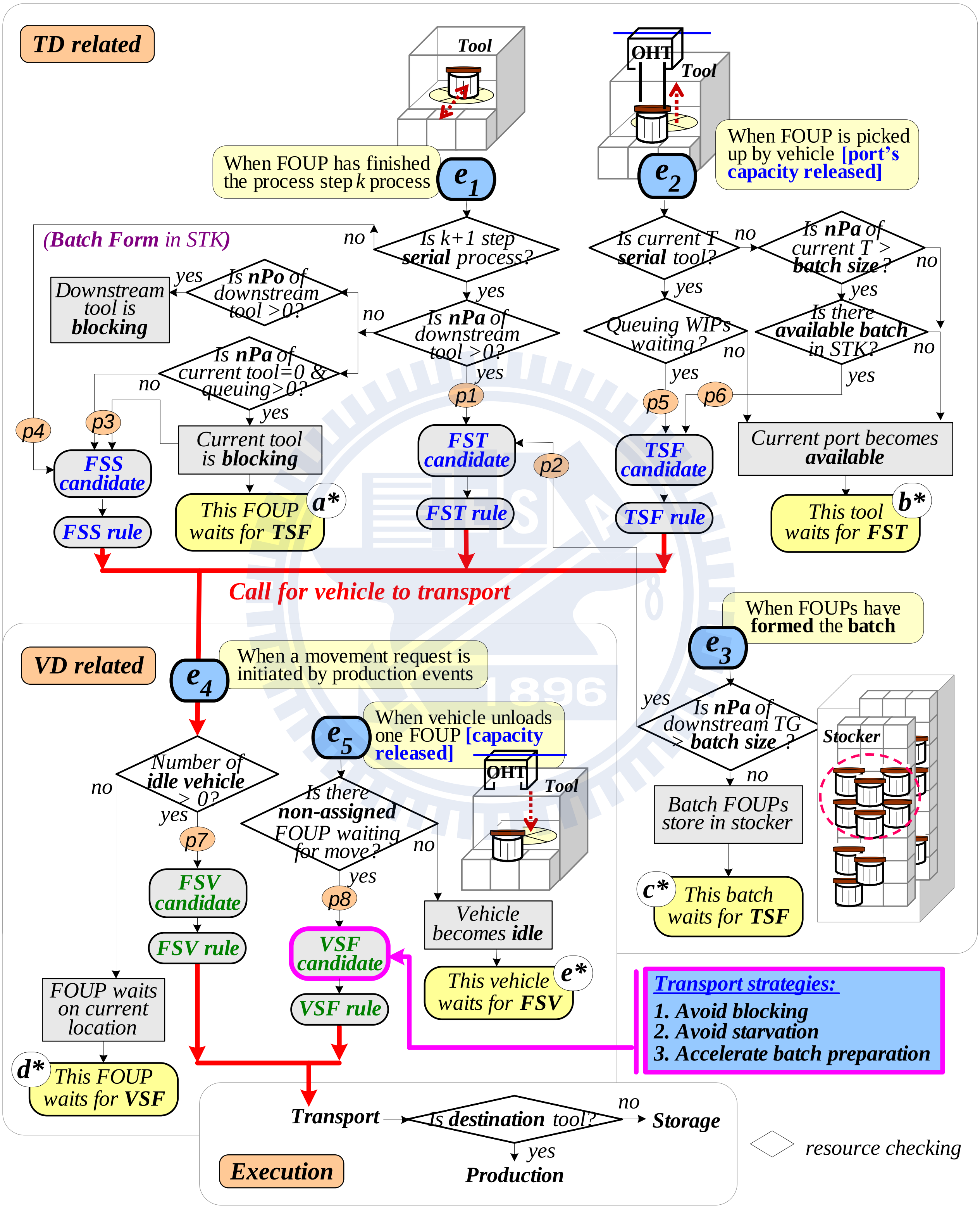


Figure 5.4 Representation of dispatching interactions

Table 5.1 *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 $y \neq \emptyset$, *candidate STK set* is y. Else ($y = \emptyset$), *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: $\mathbf{A_1B_1C_1}$**

$b = \emptyset$	$s = \emptyset$	$f = \emptyset$	*set W*
		$f \neq \emptyset$	*set f*
	$s \neq \emptyset$	$f = \emptyset$	*set s*
		$f \neq \emptyset$	If $x_3 \neq \emptyset$, *set* x_3. Else ($x_3 = \emptyset$), *set* x_6
$b \neq \emptyset$	$s = \emptyset$	$f = \emptyset$	*set b*
		$f \neq \emptyset$	If $x_2 \neq \emptyset$, *set* x_2. Else ($x_2 = \emptyset$), *set* x_5
	$s \neq \emptyset$	$f = \emptyset$	If $x_1 \neq \emptyset$, *set* x_1. Else ($x_1 = \emptyset$), *set* x_4
		$f \neq \emptyset$	If $x_7 \neq \emptyset$, *set* x_7. Else if $x_1 \neq \emptyset$ or $x_2 \neq \emptyset$ or $x_3 \neq \emptyset$, *set* x_9. Else ($x_7 = \emptyset$ & $x_9 = \emptyset$), *set* x_8.

➢**Scenario 2: $\mathbf{A_1B_1C_2}$**

$b = \emptyset$	$s = \emptyset$	*set W*
	$s \neq \emptyset$	*set s*
$b \neq \emptyset$	$s = \emptyset$	*set b*
	$s \neq \emptyset$	If $x_1 \neq \emptyset$, *set* x_1. Else ($x_1 = \emptyset$), *set* x_4

➢**Scenario 3: $\mathbf{A_1B_2C_1}$**

$b = \emptyset$	$f = \emptyset$	*set W*
	$f \neq \emptyset$	*set f*

$b \neq \emptyset$	$f = \emptyset$	*set b*
	$f \neq \emptyset$	If $x_2 \neq \emptyset$, *set* x_2. Else ($x_2 = \emptyset$), *set* x_5
➢**Scenario 4: $A_1B_2C_2$**		
$b = \emptyset$		*set W*
$b \neq \emptyset$		*set b*
➢**Scenario 5: $A_2B_1C_1$**		
$s = \emptyset$	$f = \emptyset$	*set W*
	$f \neq \emptyset$	*set f*
$s \neq \emptyset$	$f = \emptyset$	*set s*
	$f \neq \emptyset$	If $x_3 \neq \emptyset$, *set* x_3. Else ($x_3 = \emptyset$), *set* x_6
➢**Scenario 6: $A_2B_1C_2$**		
$s = \emptyset$		*set W*
$s \neq \emptyset$		*set s*
➢**Scenario 7: $A_2B_2C_1$**		
	$f = \emptyset$	*set W*
	$f \neq \emptyset$	*set f*
➢**Scenario 8: $A_2B_2C_2$**		
		set W
Rule: the longest waiting time first (LWT)		

p1~p8: path marks from Figure 5.4.

5.3.2. Dispatching Interactions

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).

(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.

5.4 Simulation Modeling

5.4.1 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 5.5. 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 hrs (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 5.2.

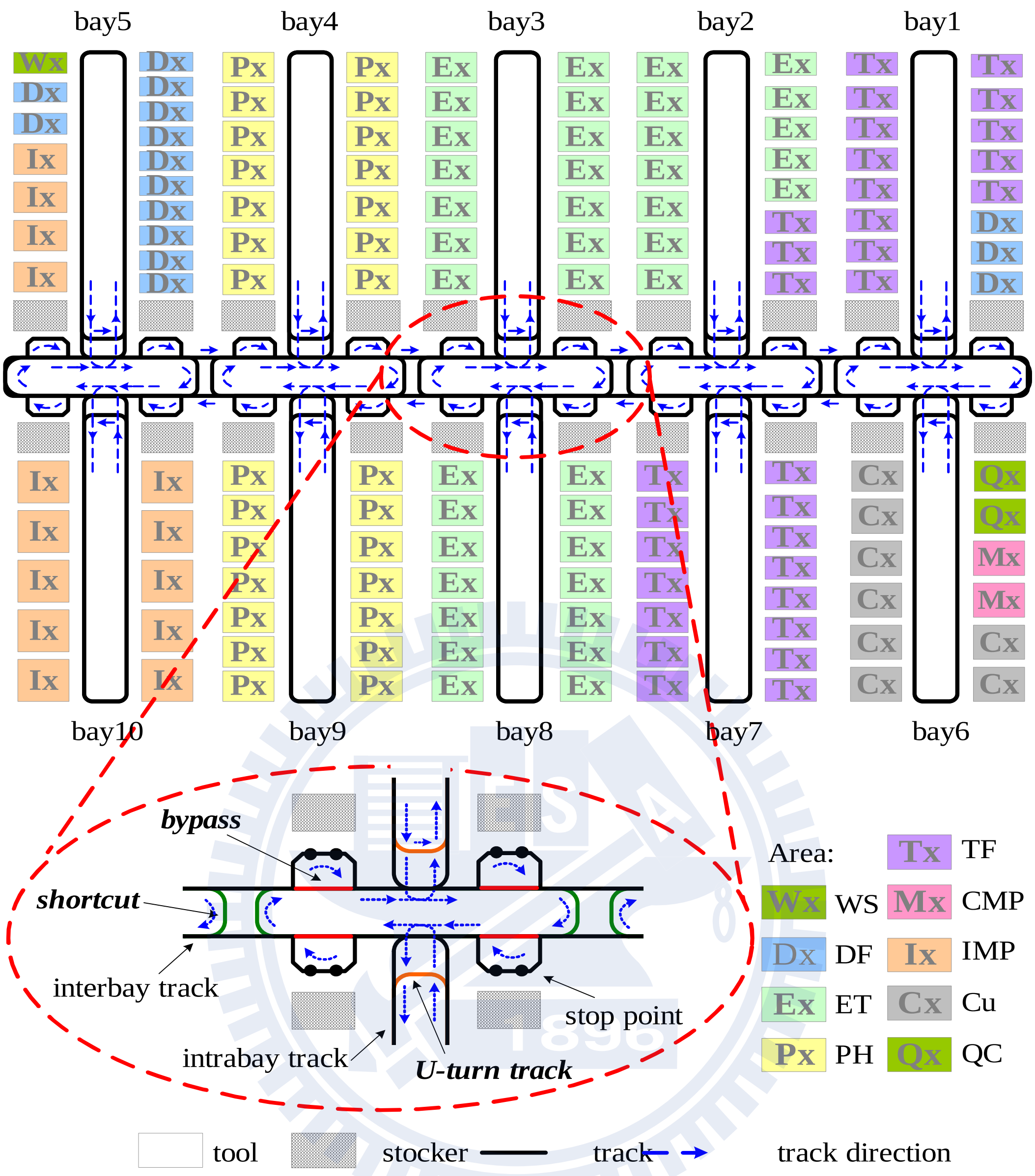


Figure 5.5 Representative layout of a 300 mm wafer fab

Table 5.2 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

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 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).

5.4.2 System Behavior

The following system behavior is described: (1) only one product described above has been implemented due to process flow confidentiality; (2) the uniform loading (UL) (Glassey and Resende [20]) 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 [19]) is used to prevent traffic collision.

5.4.3 Model Assumption

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.

5.5 Simulation Experiment

5.5.1 Performance Indices

The performance indices are outlined as follows for evaluating the proposed transport strategy under the simulation conditions described in Section 5.4.: (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" the batch preparation in Figure 5.3. A total of 19 steps BPT among process flow (736 steps) will be summarised.

5.5.2 Experiment Design

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) x 2 (B_1, B_2) x 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) x 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.

5.5.3 Results and Discussion

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 5.3 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.

Table 5.3 AVOVA for the transport strategies experiment.

(1) Response: WO

Source	Sum of Squares	DF	Mean Square	F-Value	Prob > F	
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

Source	Sum of Squares	DF	Mean Square	F-Value	Prob > F	
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

Source	Sum of Squares	DF	Mean Square	F-Value	Prob > F	
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

Further, it is necessary to examine any important interaction (Montgomery [45]), as well as the graphs of the highest-order significant interaction (ABC) to the indices. These data are shown in Figure 5.6. The slope in Figure 5.6(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 (Figure 5.6(b), Figure 5.6(c)). In addition, Figure 5.6(c) states that C_1 keeps the shorter BPT at both A and B, and this result proves the idea in Section 5.2.3.

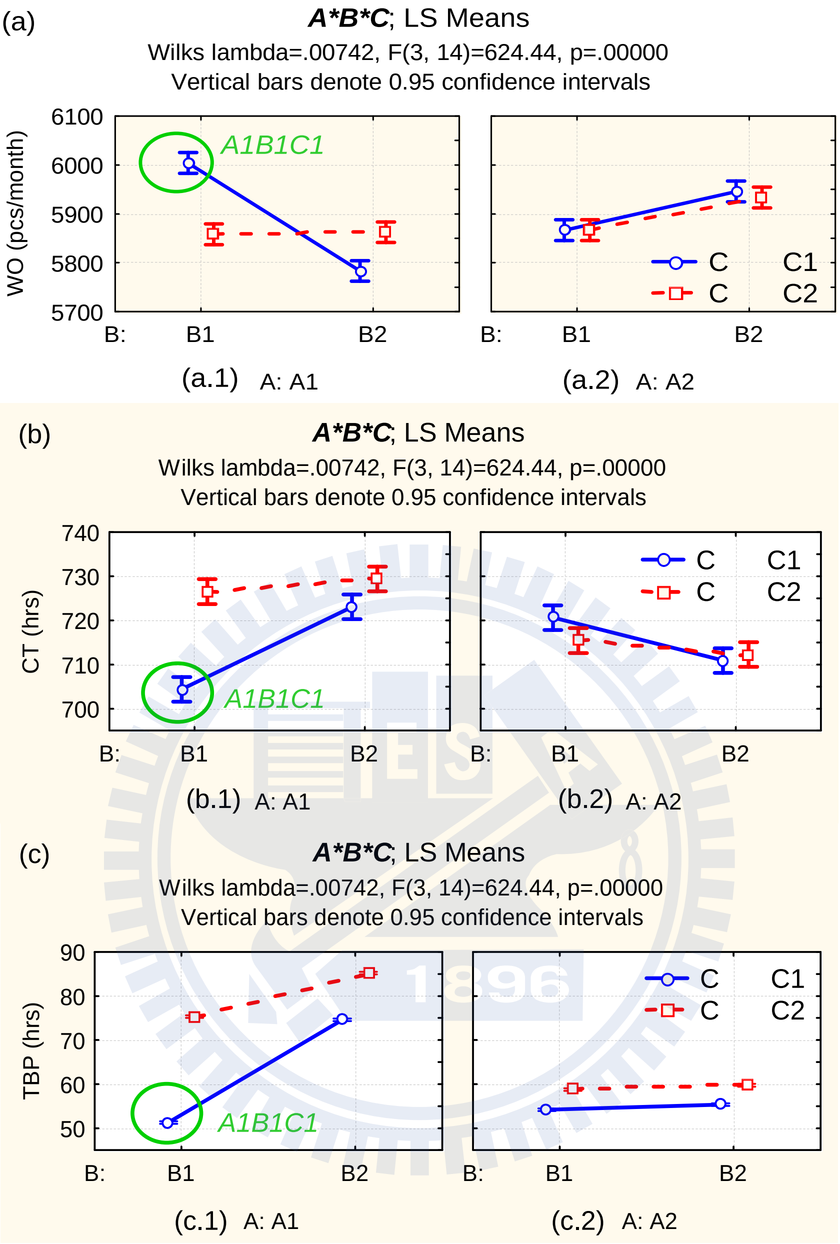


Figure 5.6 Graphs of the significant interaction

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 5.4 The results show that the differences from the proposed strategies compared to 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 [46]) was used to integrate multiple indices into one. The method makes use of an objective function *D(X)*, called the desirability function:

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

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 5.4. We can see that $A_1B_1C_1$ is the optimal transport strategy in response to the previous interactions analysis.

Table 5.4 LSD and desirability for the transport strategies experiment.

Order	Scenario			WO (pieces)		CT (hrs)		BPT (hrs)			Desirability
	A	B	C	mean	rank	mean	rank	mean	(BPT%)	rank	
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

(1) A: Blocking, B: Starvation, C: Batch Form; (2) mean: average value measured from the replications; (3) rank: different alphabet means the effects were significant at the 95% confidence level; (4) BPT%: percentage of BPT in the total time of process prepares.

From the previous section results, the following points have to be emphasised:

(1) Consideration of the tool status like 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.

CHAPTER 6 CONCLUSION AND ACHIEVEMENT

Transport strategy development is critical for the 300 mm wafer fab due to the novel transport facilities, which implies that vehicles can travel not just in one process center but all around the wide fab, and FOUP can be delivered either through stocker or tool-to-tool directly. The two transport issues were studied in this dissertation in order to bring the flexible facility a beneficial result.

The Search Range (SR) assignment is to determine how far the FOUP (or vehicle) from that vehicle (or FOUP) will be considered for transport, and then indirectly limit the *DVemp* to make the vehicle work effectively. A two-phase approach with simulation is used to develop an appropriate SR. In phase I, the transport records are collected under the number of *IV* (v) and *WF* (f) when dispatching occurs, and then the average and standard variation of *DVemp* under v and f can be summarized for observing the *DVemp*'s trend and distribution. The *DVemp*'s trend showed that the number of *WF* (f) and *IV* (v) in the system will affect the *DVemp* when dispatching successfully. The *DVemp*'s distribution showed that *DVemp* gathered between the intervals from -2.5σ to 3σ of the average distance of *DVemp*. Further, phase II extends this result to design and evaluate levels of SR. The SR are designed by average *DVemp* ($\overline{Vd}_v, \overline{Fd}_f$) plus multiples of standard deviation of *DVemp* (VS_v, FS_f) under different numbers of *WF* (f) and *IV* (v) in each system loading: MR, and also to test if SR is required for dispatching (SR_0). The simulation results showed that SR affects performance significantly, and the longer SR like SR_3 is applicable in a light system such as MR_1, and in a heavy system such as MR_2 and MR_3, the shorter SR like $SR_{1.5}$ is appropriate. That also means ignoring the *WFs* or *IVs* far from *V* or *F* by assigning an appropriate SR can improve performance.

Furthermore, the *demand driven* transport strategies in Integrated Dispatching (ID) is researched for the fully-auto manufacturing and the challenge transport mode. Three transport strategies involved in Vehicle Dispatching (VD), namely, the *avoid blocking*, *avoid starvation*, and *accelerate batch preparation*, were developed and implemented in the Tool and Vehicle Dispatching Integrated (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 three-factor full-factorial with 2^3 designs is 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 to fully support production like obviating production obstacles and avoiding capacity loss.

Therefore, these topics do not only involve the fully-automated manufacturing characteristic in the 300mm wafer fab, but also further provides the solution for practitioners involved in dispatching software development. For practical implementation, MES could maintain a list of *prioritized 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 SR and ID strategies, the production characteristic focused on production areas where there are particular restrictions might be implemed into TD for further improving the proposed TVDI architecture.

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Appendix A

The Process flow information using in integrated dispatching (ID) study was as follows.

Layer	Production functions (area)										Sub.
	s(t): step number (process time)										
	WS	TF	ET	DF	DF*	PH	IMP	CMP	CU	QC	
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.