Effectiveness of Vehicle Dynamic Reassignment Dispatching in Interbay Material Handling System

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Abstract. This paper proposed a multi-attribute of intelligence dynamic scheduling method in Interbay automated material handling system (AMHS), this method can response to OHS idle status and wafer lot's request in real-time, then developed an optimal re-assignment, thus promoting the performance of the Interbay material handling system. Experiment results demonstrate that the proposed rule has better comprehensive performance than traditional dispatching rules.

Keywords: Multi-attribute; Dynamic scheduling; Interbay System; AMHS.

1. Introduction

The semiconductor wafer fabrication systems are different from traditional Flow-shop and Job-shop manufacturing systems, which has many distinguished characteristics, such as re-entrant flow, sophisticated processing steps, mass and mixed work-in-process (WIP), long production cycle time and high capital investment [1]. As the semiconductor industry moves from 200mm to 300mm and even 450mm, the traditional manual material handling cannot be competent to the intensive work. So the AMHS has been widely adopted by the semiconductor manufacturing fab in the world [2]. Generally, the semiconductor manufacturing AMHS is composed of two types of material handling systems: one is the Interbay system, the other is the Intrabay system (show in Fig.1). In a typical 300mm semiconductor manufacturing FAB, the Interbay material handling system transport the wafer measured by a lot. Each lot contains a certain number of wafers, at most 25. The lot is moved by Front-Opening Unified Pods (FOUP).

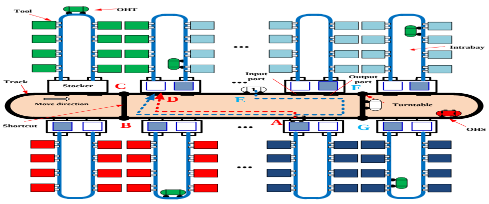

Fig.1 Separate layout structure diagram of AMHS

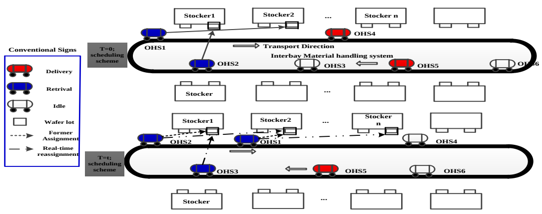

Fig.2 Real - time scheduling process

2. Problem description

Interbay material handling system is the key subsystem of AMHS, the efficiency improvement of Interbay material handling system is of great importance on system performance metrics, such as the average cycle time, tool utilization, etc. [1]. Wei et al. [3], Jeong et al. [4] think the single attribute scheduling rules can't satisfy the multi-attribute system in real environment. Kim et al. [5], Sun et al. [6] considered multi-attribute in their cost equations, but the weights of which are fixed and can't vary in real time as the manufacturing system status changed.

In this paper, we proposed a multi-attribute of intelligence dynamic scheduling (*MIDS*) method in Interbay AMHS in real-time, this method can response to *OHS* idle status and wafer lot's request in real-time, then developed an optimal re-assignment, thus promoting the performance of the Interbay material handling system. Fig.2 above describes the real-time reassignment dispatching logic. There are two jobs to be delivered at time $T=0$, through the assignment, *OHS* 1 and *OHS* 2 are assigned Stocker 2 and Stocker 1, respectively. If a new wafer lot is created on stocker n at the time $T=t$, through the real-time reassignment dispatching rules, *OHS* 1 was assigned to the newly lot, *OHS* 2 and *OHS* 3 are reassigned to Stocker 2 and Stocker 1, respectively. This method we applied in our study, Waiting and Assigned wafer lot are included as candidates for reassignment. This differs from most other studies where only waiting wafer lot are considered in dispatching.

3. Modeling and formulation

To give a clear meaning in the cost equation and some other mathematical models, the below notations are used in the following sections.

$dis(i,j)$: the distance between the point when $OHS\ j$ receive the request to the point where lot i located (That is the distance from OHS vehicle j to the starting location of lot i).

wt_i: is the time between the decision-making moment of wafer lot i to the arriving moment of OHS. APT_i : the sum of processing time of all operations of wafer lot i.

niq_i: denote the input buffer queue length of wafer lot i's destination stocker k.

noq_i : denote the output buffer queue length of wafer lot i's destination stocker k.

N_O: the capacity of the input buffer of stocker k. N: the number of stockers in the Interbay system . RT_i: the remaining time before the due date of wafer lot i.

VN: the total number of vehicles in the Interbay system. N_I: the capacity of the input buffer of stocker k . m : the total number of waiting wafer lots in the Interbay system.

RP_i: the sum processing time for remaining operations of wafer lot i .

P: the number of wafer lots that have been completed all the processing in the system.

Nwt: the number of wafer lots that their waiting time are greater than the expected average waiting time AW. cw_q : the average waiting time of wafer lot q.

BS_{In}: the input buffer level of stocker S. BS_{Out}: the output buffer level of stocker S.

3.1 Multi-parameter cost function

In the wafer lot transport cost model, we consider four important performance metrics, including wafer lot distance factor, wafer lot due date satisfaction factor, wafer lot waiting time factor, stocker input and output buffer status factor. c_{ij} is calculated by the below weighted multi-parameter cost function.

$$c_{ij} = w_1 \cdot DIS_{ij} + w_2 \cdot DD_i + w_3 \cdot (1 - WT_i) + w_4 \cdot BS_i \tag{1}$$

In order to integrate these dfferent variables (parameter metrics), they are first normalized as parameters by dividing itself to the maximum possible value.

(1) DIS_{ij} is the transport distance factor

$$DIS_{ij} = \frac{dis(i,j)}{arg \max\limits_{i\in n, j\in m} (dis(i,j))} \tag{2}$$

(2) DD_i is the due date satisfaction factor, is calculated by the below function.

$$DD_i = \frac{RT_i}{RP_i \cdot Sla_{max}} \tag{3}$$

(3) WT_i is the wafer lot waiting time factor. wt_{max} is the maximum waiting time, is a constant value greater than any possible wt_i

$$WT_i = \frac{wt_i}{wt_{max}} \tag{4}$$

(4) BS_i is the stocker input and output buffer status factor. $RS_i = \frac{niq_i}{N_I}$ is the normalized buffer level of the input buffer in the destination stocker, and $RSO_i = 1 - \frac{noq_i}{N_O}$ is the normalized buffer level of the output buffer in the source stocker.

$$BS_i = RSI_i \cdot RSO_i \tag{5}$$

w_1 , w_2 , w_3 , w_4 are adaptively adjusted by T-S fuzzy logic-based multi-parameter weight modification model, which will discussed in the following section.

3.2 T-S fuzzy logic based multi-parameter weight modification model

The four fuzzy input variables are the interbay systems load ratio, wafer lots due date factor, wafer lots waiting time factor, Interbay system buffer load balance factor. The input variables represent the overall system dynamic status.

(1) Interbay system load ratio x_1, measuring the current transportation load of Interbay material system.

$$x_1 = \frac{\sum_{S=1}^{N} WN_S}{VN} \tag{6}$$

(2) Wafer lots due date factor x_2 , x_2 is used to measure the wafer lot waiting at the output buffer due date satisfaction .

$$x_2 = \sum_{i=1}^{m} \frac{RT_i}{RP_i \cdot Sla} \cdot \frac{1}{m} \tag{7}$$

$$Sla = \sum_{i=1}^{P} \frac{CT_i}{APT_i} \cdot \frac{1}{P} \tag{8}$$

Sla is the due date slack coefficient of completed wafer lots .

(3) Wafer lots waiting time factor x_3, x_3 is used to measure the ratio that the wafer lots whose waiting time is greater than the expected average waiting time AW.

$$x_3 = \frac{Nwt}{m} \tag{9}$$

$$AW = \sum_{q=1}^{P} \frac{cw_q}{P} \tag{10}$$

(4) Interbay system buffer load balance factor x_4 , x_4 is used to measure the probability of stocker buffers blocking or starvation.

$$x_4 = \frac{1}{N} \cdot \sum_{S=1}^{N} [(B_{si} - \bar{B}_{in})^2 + (B_{so} - \bar{B}_{out})^2] \tag{11}$$

Where $B_{si} = e^{[1-(\frac{BS_{In}}{N_I})^2]}$, $B_{so} = e^{[1-(\frac{BS_{Out}}{N_O})^2]}$, $\bar{B}_{in} = \frac{1}{N} \cdot \sum_{S=1}^{N} B_{si}$, $\bar{B}_{out} = \frac{1}{N} \cdot \sum_{S=1}^{N} B_{so}$.

Select triangular and trapezoidal membership functions to establish the input variables membership functions, the four input variables are showed below figure 3.

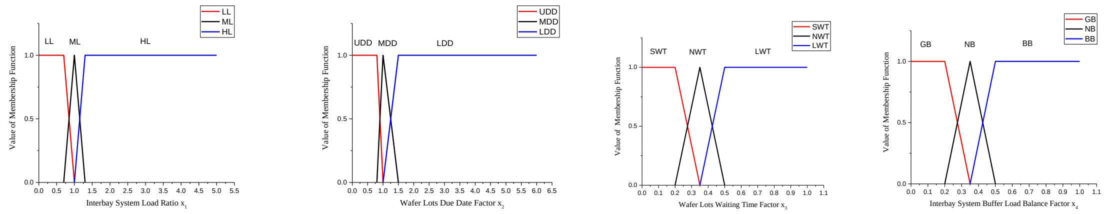

Fig.3 The membership function

3.3 Hungarian algorithm (HA) based OHS reassignment dispatching policy

The problem of OHS vehicle dispatching in the Interbay material handling system is a special 0-1 integer programming problem in operations research, which can be formulated as a mathematical model below. Assume that at the time T=t, there are n waiting wafer lots (available lots) and m available vehicle OHS (Include idle and retrieval status vehicles).

$$Min\{\sum_{i=1}^{n} \sum_{j}^{m} c_{ij} X_{ij}\} = Mini(C \cdot X) \tag{12}$$

$$\sum_{j=1}^{m} X_{ij} = 1 \ , for\ i = 1 , 2 , \ldots , n \ , \sum_{i=1}^{n} X_{ij} = 1 , \ \ for\ i = 1 , 2 , \ldots , m \tag{13}$$

Where

$$C = \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1m} \\ C_{21} & C_{22} & \cdots & C_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ C_{n1} & C_{n2} & \cdots & C_{nm} \end{bmatrix}$$

We choose hungarian algorithm to solve the reassignment problem in this study. Hunrarian algorithm is an effective method to solve the optimal assignment problem.

4. Simulation models and the analysis of results

To evaluate the scheduling method we proposed in this paper, discrete event simulation model are constructed using Arena software on a Intel® Core™ i-5 processor (2.35 GHz clock). The configuration of the wafer fab considered in this paper is about 24 Intrabays and one Interbay. The total distance of the loop is 456 meters. We choose some traditional scheduling policies to compare with the WIDS method in this paper. These scheduling policies are showed in table 1.

Table 1 Scheduling Policies

Scheduling polices	description
SDFS	Choose the FOUP which has the shortest distance between the vehicle
FIFO	Choose the FOUP which arrived in the queue at the earliest time
LWNQ/M	Choose the FOUP whose queue at the next Bay it will visit with the least amount of expected work per process tools
WIDS	Proposed in this paper

Now we assume that there are 4 FOUPs (A, B, C, D) are waiting for moving by three OHSs (V1, V2, V3), the data about these FOUPs are described below table 2. Table 2 is about the due date satisfaction factor of FOUP i $(DD_i, i = A, B, C, D)$, waiting time factor of FOUP i $(WT_i, i = A, B, C, D)$, the destination input and output buffer status factor about FOUP i $(BS_i, i = A, B, C, D)$. Table 3 are the distance of FOUP i to the OHS.

Table 2 Data of FOUP i

FOUP Type	DD_i	WT_i	BS_i
A	0.67	18.3	0.79
B	0.84	19.2	0.62
C	0.78	18.7	0.85
D	0.45	20.3	0.57

Table 3 Distance of FOUP i to OHS *j*

FOUP Type	*V1(meters)*	*V2*	*V3*
A	113	138	81
B	100	125	56
C	87	24	119
D	119	56	151

Case 1: If we choose the *SDFS* policy, the dispatching results is

$$\begin{bmatrix} 113 & 138 & 81 & \infty \\ 100 & 125 & 56 & \infty \\ 87 & 24 & 119 & \infty \\ 119 & 56 & 151 & \infty \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

That means FOUP D is not be selected to transfer, but FOUP D has the most urgent due date, most longest wait time among these 4 FOUPs, this results may lead the low due date satisfactory, so the SDFS policy is not the most effective scheduling in this time.

Case 2 : If we choose FIFO policy, the dispatching result is

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

That means FOUP D is not be selected to transfer, but FOUP D has the most longest wait time among these 4 FOUPs, this results may lead the increasement the cycle time, wait time, WIP, so the FIFO policy is not the most effective scheduling in this time.

Case 3: If we choose LWNQ/M policy , the dispatching result is

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

That means FOUP D is not be selected to transfer, but FOUP D has the less probably be blocked in the destination bay among these 4 FOUPs, this result may lead the block, so the LWNQ/M policy is not the most effective scheduling in this time.

Case 4: If we choose WIDS policy, the dispatching result is

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

That means FOUP D is selected to transfer, so the WIDS policy is the most effective scheduling in this time.

Through above discussion on the scheduling policies applied in the real fab, we find the proposed dispatching rule WIDS is the most effective scheduling policy. The WIDS method outperforms the most popular traditional dispatching rule above, we can get less cycle time, higher due date satisfactory, less block in the system when applied the proposed rule.

5. Conclusion

The proposed a multi-attribute of intelligence dynamic scheduling method in Interbay automated material handling system are described above, through the experiments on 4 different scheduling policies applied in the real fab, we find the proposed dispatching rule WIDS is the most effective scheduling policy. Experiment results demonstrate that the proposed scheduling rule has better comprehensive performance than traditional dispatching rules.

In the future work, we would like to extend the proposed method for more cases in order to implement it in practical wafer fabrication. Another further work is that we will modify this proposed method and apply it in the unified AMHS in 300 mm semiconductor wafer fab .

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