A Fuzzy Scheduling System for Dedicated Machine Constraint

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Abstract

In this paper, we propose the Fuzzy Scheduling System (FSS) to deal with the dedicated machine constraint. The constraint of having a dedicated machine for photolithography process is the new issue introduced in photolithography machinery due to natural bias. If we randomly schedule the wafer lots to arbitrary photolithography machines at the first photolithography stage, then the load of all photolithography machines might become unbalanced. It is the main contributor to the complexity and uncertainty of the semiconductor factory. The FSS is to select the best photolithograph machines for each wafer lot at the first, unconstrained, stage to tackle this dedicated machine constraint and to maintain the load balancing among photolithography machines.

Keywords: Dedicated Machine Constraint, Fuzzy Scheduling System, Photolithography Machine, Semiconductor manufacturing.

1. Introduction

In a semiconductor factory, one wafer lot passes through hundreds of operations, and the processing procedure takes a few months to complete. The operations of semiconductor manufacturing incrementally develop an IC product layer by layer. One of the new challenges in the semiconductor manufacturing systems is the dedicated photolithography machine constraint which is caused by the natural bias of the photolithography machine. Natural bias will impact the alignment of patterns between different layers. The smaller the dimension of the IC products (wafers), the more difficult they will be to align between different layers. A study terms the dedicated constraint as machine dedication policies [1].

If we randomly schedule the wafer lots to arbitrary photolithography machines at the first photolithography stage, then the load of all photolithography machines might become unbalanced. The unbalanced load is the main contributor to the complexity and uncertainty of the semiconductor factory. Fig. 1 describes the dedicated machine constraint. For example, with the dedicated machine constraint, when the wafer lots enter the photolithography process stages and if the wafer lots have been dedicated to the machine **X**, they need to be processed by and wait for **X**. The wafer lot can not be processed by other machines, e.g., the machine **Y**, even if **Y** is idle. On the other hand, when the wafer lots enter into those non-photolithography process stages, without this dedicated machine constraint, the wafer lots can be processed by any machine of **A**, **B**, or **C** as long as it becomes idle.

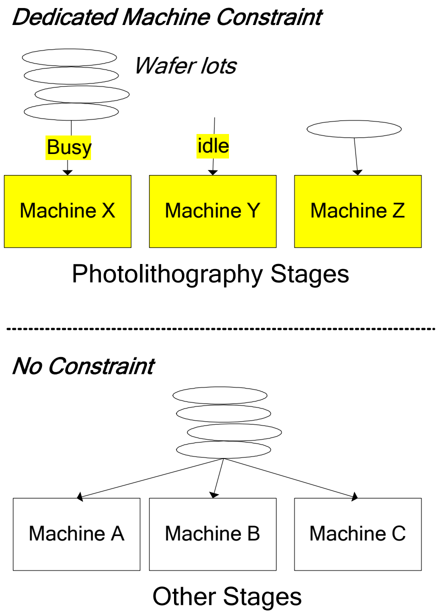


Fig. 1: Dedicated machine constraint.

Fuzzy logic introduced by Zadeh has been applied to various industrial problems. There has been some research to model scheduling problems within a fuzzy framework [2]. The advantage of the fuzzy logic system approach is that it incorporates both numerical results from a previous solution or simulation and the scheduling expertise from experiences. One fuzzy logic based scheduling system has recently been developed for the semiconductor manufacturing [3].

In this paper, Fuzzy Logic is applied to the Fuzzy Scheduling System model to select the best machine for a wafer lot at the first, unconstrained, photolithography stage to tackle the dedicated machine constraint and maintain the load balancing among photolithography machines.

2. Fuzzy Scheduling System

Scheduling a wafer lot to a dedicated machine at the first photolithography stages, the Fuzzy Scheduling System (FSS) considers some fuzzy factors of the photolithography machines such as Load, Utilization, and so on. The FSS uses the Resource Schedule and Execution Matrix (RSEM) [4, 5, 6, 7, 8, 9] to manipulate the scheduling process. The fuzzy scheduling model is presented in this Section

2.1. Fuzzy Model

The fuzzy logic includes the concepts of fuzzy sets, linguistic variables, and possibility distributions [10]. A fuzzy set is a set to allow objects to take partial membership in vague concepts. The membership value is a real number between 0 and 1 which is to represent the degree of an object belongs to a fuzzy set. The membership function of a fuzzy set A is denoted as μ_A. A linguistic variable is a qualitative variable to express the linguistic terms. It is also a quantitative variable to a corresponding membership function. When a fuzzy set is assigned a linguistic variable, it imposes that an interval unknown value is assigned to this linguistic variable, i.e., it constrains the possible values of the linguistic variable called the possibility distribution.

The Fuzzy Scheduling System (FSS) is a scheduling system uses the membership functions and rules to reason about the data. We apply the scheduling knowledge to special values of the input variables to produce the values of the output variable. Generally, the process of the FSS consists of four subprocesses: fuzzification, inference, composition, and defuzzification.

2.2. Resource Schedule and Execution Matrix

In this section, the procedure and algorithm of the Resource schedule and Execution Matrix (RSEM) is summarized in this Section. The RSEM consists of three modules including the *Task Generation*, *Resource Calculation*, and *Resource Allocation* modules.

The first module, *Task Generation,* is to model the tasks for the scheduling system. For example, in the semiconductor factory, the tasks are the procedures of processing wafer lots, starting from the raw material until the completion of the IC products. We generate a two-dimension matrix for the tasks that are going be processed by machines. We can formalize the task matrix Λ as follows: there are a finite set $\boldsymbol{\sigma} = \{S_1, \ldots, S_n\}$ *of n* steps and a finite set $\boldsymbol{\tau} = \{T_1, \ldots, T_m\}$ *of m* tasks (wafer lots). Therefore, the matrix looks as follows:

$$
\begin{array}{c|ccccccccccc}
 & S_1 & S_2 & . & . & . & . & . & S_j & . & . & S_m \\
\hline
T_1 & r_1 & r_2 & r_3 & .. & .. & .. & r_k. & .. & .. & .. & .. \\
T_2 & & r_3 & r_4 & .. & .. & r_k & .. & .. & .. & .. & .. \\
. & & & & & & & .. & .. & & & \\
T_i & & & & & r_3 & r_4 & .. & .. & r_k & .. & \\
. & & & & & & & . & . & & & \\
T_n & & & & & .. & .. & r_k & .. & .. & .. &
\end{array}
$$

The symbol, r_k in the matrix Λ is to represent the fact that the task T_i needs of the resource (machine) r_k at the time S_j. If T_i starts to be processed at S_j and the total step numbers of T_i is p, we will fill its pattern into the matrix from $\Lambda[t_i, s_j]$ to $\Lambda[t_i, s_{j+p-1}]$. All the tasks, $\boldsymbol{\sigma}$, follow the illustration above to form a task matrix Λ in the task generation module. To represent the dedicated machine constraint in the matrix for this research, the symbol r_k^x, a replacement of r_k, is to represent that T_i has been dedicated to number x of type k machine at S_j.

The *Resource Calculation* module could provide the value of each dimension as the fuzzy factors for the scheduling rules of the *Resource Allocation* module, e.g., the Load and Utilization of machines by equation (1) and (2) in Section 2.3, respectively.

The FSS schedules the wafer lots to the best machine according to the fuzzy scheduling rule in this *Resource Allocation* module. To represent the situation of waiting for r_k ; i.e., when T_i can not take the resource r_k at S_j, then we will not only insert w_k in the pattern of T_i, but also need to shift the following pattern to the next step in the task matrix Λ. The following matrix shows the situation.

$$
\begin{array}{c|ccccccccccc}
 & S_9 & S_{10} & S_{11} & S_{12} & S_{13} & S_{14} & .. & .. & S_j & .. & S_m \\
\hline
 & & & & & .. & .. & & & & & \\
T_i & .. & \boxed{\boldsymbol{r_2^1}} & \boldsymbol{r_4} & r_5 & r_6 & r_7 & .. & .. & & & \\
T_{i+1}' & .. & \boxed{\boldsymbol{w_2}} & \boldsymbol{r_2^1} & \boldsymbol{r_4} & r_6 & r_5 & .. & .. & .. & .. & \\
.. & & \uparrow & \rightarrow & \rightarrow & \rightarrow & \rightarrow & & & & &
\end{array}
$$

2.3. Load Balancing Factors

To deal with the dedicated machine constraint and to keep the balancing load of the photolithography machines, the Fuzzy Scheduling System (FSS) combines the factors, $X_1 \sim X_5$, to evaluate the ability of the machines to each wafer lot. The fuzzy sets of each university of discourse are labeled as the terms set shown in Table 1. Each factor is described as follows:

Table 1 Definition of fuzzy sets

Linguistic variable	**Term set**
X_1:Load	SL, ML, LL
X_2:Utilization	SU, MU, LU
X_3:Service level	SS, MS, LS
X_4:Yield	SY, MY, LY
X_5:Setup time	SST, MST, LST

X_1: **Load**, *it is the total service demand of the wafer lots limited to this machine to the capacity of the machine could provide within a time period. The fuzzy sets of this factor will be SL: below the average, ML: around the average, LL: heavier than average.*

X_2: **Utilization**, *it represents the workload of machines. It is a short-term factor. The fuzzy sets of this factor will be SU: below the average, MU: around the average, LU: larger than average.*

X_3: **Service Level**, *how fast could the wafer lot be served by the machine? It is related to the priority of the wafer lot for the machine. The fuzzy sets of this factor will be SS: better than average, MS: around the average, LS: below the average.*

X_4: **Yield**, *it is the yield of the machine for the products. The fuzzy sets of this factor will be SY: better than average, MY: around the average, LY: below average.*

X_5: **Setup time**, *e.g., it could depend on whether the required mask or material is on the machine or not. If the wafer uses the same mask as the current mask on the machine, it could save the setup time due to the setup change in the machine. The fuzzy sets of this factor will be SST: save the setup time, MST: normal case, LST: waste setup time.*

and the fuzzy rule of scheduling is defined as that each wafer lot will be assigned to the machine m_{best} at the first, unconstrained, photolithography process stage.

DEFINITION. Fuzzy Scheduling Rule.

let Fuzzy set $X_{ij} \in U_j, x_{ij} \in U_j$, $i = 1, \ldots, m$, $j = 1, \ldots, 5$.
m = the number of photolithography machines in the system,

$$\Rightarrow \text{let } \mu_{A_i} = \mu_{X_{i1} * \ldots * X_{i5}}(x_{i1}, \ldots, x_{i5}) = \min[\mu(x_1), \ldots, \mu(x_5)].$$

$$m_{best} = \min(\mu_{A_i}).$$

Load and **Utilization** can be calculated by the following equations:

$$Load(m) = \frac{\sum\{n(w) \mid w \in W, ph(w) = m\} \times r(w)}{wph(m) \times t} \ldots\ldots.(1)$$

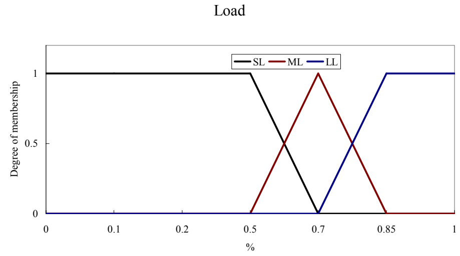
$$Utilization(m) = \frac{\sum\{n(w) \mid w \in W, ph(w) = m, s_k(w) < t\}}{wph(m) \times t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

m: photolithography machine
W: wafer lots in process (WIP)
n(w): wafer quantity of w
ph(w): wafer lot $w \in W$*, limited to the photo machine m*
r(w): remaining photolithography stages of wafer lot w
t: time duration, usually will be a 24-hour day.
$s_k(w)$*: slack time for wafer lot w*
wph(m): wafer per hour, the productivity index of machine m.

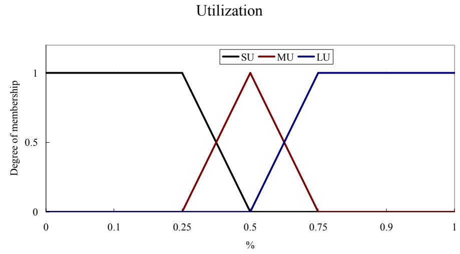
Load is defined as the rate of the wafer lots limited to machine m multiplied by the remaining layers of photolithography stage (demand) to the capacity of the machine m (provide). Load is a relative parameter, representing the load of the machine and wafer lots limited to one machine.

Utilization is defined as the rate of the wafer lots limited to machine *m* and the capacity of *m*. Utilization > 1 means that *m* is overloaded, i.e., some of the wafer lots which are waiting for *m* will take more time to exit the system than the their original plan. Sometimes, they will never be on time for delivery, even if these wafer lots could always get the highest priority for the stages following.

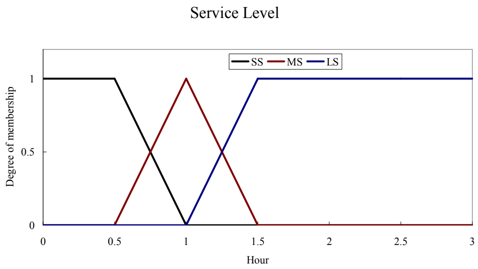
The membership functions for each fuzzy set are triangular except at extreme left and right as show in Fig. 2 (a)-(e).



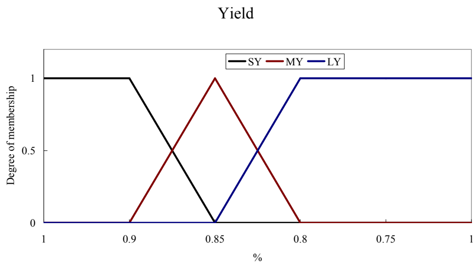
(a) Load



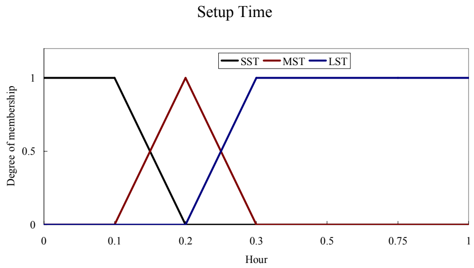
(b) Utilization



(c) Service Level



(d) Yield



(e) Setup Time

Fig. 2: Membership functions of the scheduling factors.

3. Conclusion

The proposed FSS system based on RSEM to the issue of the dedicated photolithography machine constraint has been presented. The advantage of FSS system is that it could incorporate both numerical and linguistic variables. The experienced managers could easy set the membership functions of these fuzzy sets according to their special need manually.

In the future work, we want to apply machine learning to set the weight of the fuzzy factors automatically depending on the status of the production line and the historical contracts.

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5. References

[1] E. Akcalt, K. Nemoto, and R. Uzsoy, “Cycle-time improvements for photolithography process in semiconductor manufacturing,” *IEEE Trans. on Semiconductor Manufacturing,* pp. 48-56, 2001.
[2] P. Srinoi, E. Shayan, F. Ghotb, “ Scheduling of Flexible Manufacturing Systems Using Fuzzy Logic,” http://www.swin.edu.au/iris/pdf/profiles/PramotSrinoi.pdf
[3] N. Chaudhry, J. Moyne, and E. A. Rundensteiner, “Utilizing Fuzzy Data and Rules for Discrete Control of Semiconductor Manufacturing Processes," http://citeseer.ist.psu.edu/183597.html. 1998.
[4] A. M. D. Shr, A. Liu, and P. P. Chen, “A Load Balancing Scheduling Approach for Dedicated Machine Constraint,” *Proc. of ICEIS 2006 Conference,* Paphos, Cyprus, pp. 170-175, May 2006.
[5] A. M. D. Shr, A. Liu, and P. P. Chen, “A Heuristic Load Balancing Scheduling Method for Dedicated Machine Constraint,” *Proc. of IEA/AIE'06 Conference,* Annecy, France, June 2006, Lecture Notes in Artificial Intelligence (LNAI) 4031, M. Ali and R. Dapoigny Eds. pp. 750–759, June 2006. Springer-Verlag, Berlin Heidelberg.
[6] A. M. D. Shr, A. Liu, and P. P. Chen, “Load Balancing among Photolithography machines in Semiconductor Manufacturing,” *Proc. of IEEE IS'06 Conference,* London, England, September 2006.
[7] A. M. D. Shr, A. Liu, and P. P. Chen, “A Load Balancing Method for Dedicated Photolithography Machine Constraint,” *Proc. of BASYS'06 Conference,* Niagara Falls, Ontario, Canada, September 2006.
[8] A. M.D. Shr, A. Liu, and P. P. Chen, “A Solution for Dedicated Machine Constraint in Semiconductor Manufacturing,” *Proc. of SMC 2006 Conference*, Taipei, Taiwan, October 2006.
[9] A. Liu, P. P. Chen, A. M.D. Shr, and Y.-R. Cheng, “Using a Multiagent Scheduling System for Dedicated Machine Constraint in Semiconductor Manufacturing,” *Proc. of SMC 2006 Conference*, Taipei, Taiwan, October 2006.
[10] J. Yen, “Fuzzy Logic: A Modern Perspective,” *IEEE Trans. on Knowledge and Data Engineering*, Vol 11, No. 1, January 1999.