Proceedings of the 2016 Winter Simulation Conference
T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T. Huschka, and S. E. Chick, eds.

DEDICATION LOAD BASED DISPATCHING RULE FOR PHOTOLITHOGRAPHY MACHINES WITH DEDICATION CONSTRAINT

Yong H. Chung
Kang H. Cho
Sang C. Park

Department of Industrial Engineering
Ajou University
Woncheon, Suwon, KOREA

Byung H. Kim

VMS Solutions Co., Ltd.
Hanshin S-MECA 611, Gwanpyeong, Yuseong-gu
Daejeon, 305-509, KOREA

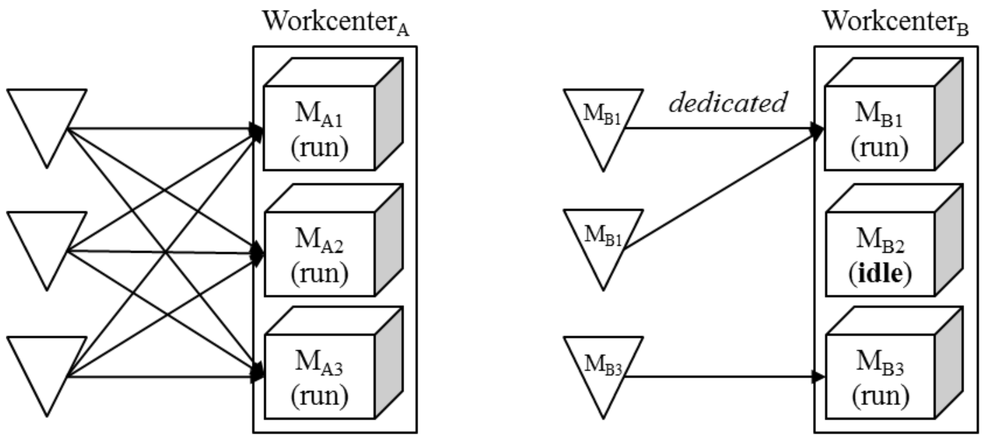
ABSTRACT

This paper addresses a semiconductor wafer fabrication (FAB) scheduling problem with dedication constraint. Under dedication constraint, a fabrication lot must be processed using the same photo machine at all photolithography (photo) steps. To solve the utilization decrease of photo machines by dedication, we propose a dedication load as the sum of the workload of lots dedicated to each photo machine. When a photo machine becomes available to process a new lot, if its dedication load is less than the average of similar machines, then the photo machine will be assigned to process the first step of a new lot in the event that one is available. To prove the performance of this proposed dispatching rule, we developed a simulation model based on MIMAC6, and conducted a simulation by using MOZART®. The proposed dispatching rule was implemented and outperformed conventional dispatching rules.

1 INTRODUCTION

Semiconductor wafer fabrication (FAB) is one of the most complicated manufacturing systems because of the reentrant processing flow, sequential dependent setup, and various machine types. In wafer FAB, chips are manufactured through processes that consist of hundreds of steps such as etching, diffusion, ion implantation, and photolithography (photo) (Lin et al. 2005). Among these various steps, the photo step is usually considered as the bottleneck step because of the expensive photo machine. Therefore, the performance of photo machines determines the performance of a FAB, and thus it is necessary to maintain full utilization of photo machines (Sha et al. 2006).

To maximize the utilization of photo machines, it is necessary to consider natural bias that significantly affects the alignment of patterns between different photo steps (Pham, H. N. A. et al. 2008). The natural bias has a negative effect on the quality and yield of products. To overcome this problem, most manufacturers have applied dedication constraint where a lot must be processed using the same photo machine at all photo steps. If the constraint is not managed properly, it may decrease the utilization of the photo machines. Figure 1 shows an example of a problem case caused by dedication constraint. We assumed that workcenter$_A$ and workcenter$_B$ are arranged for non-photo steps and photo steps, respectively. As shown in Figure 1(a), it is possible to select any waiting lot in the queue of workcenter$_A$, when one of the machines (e.g., M_{A1}, M_{A2}, M_{A3}) included in workcenter$_A$ becomes available. On the other hand, waiting lots in the queue of workcenter$_B$ have to be processed by a photo machine that is limited by dedication constraint. As the situation shown in Figure 1(b) indicates, photo machine M_{B2} cannot process any lot in the queue of workcenter$_B$ as there are lots waiting for M_{B1} and M_{B3}.



(a) Non-photo steps without machine-dedication constraint

(b) Photo steps with machine-dedication constraint

Figure 1: An example of problem case caused by dedication.

As dedication constraint is strongly related to the utilization of a photo machine, various studies have been conducted on wafer FAB scheduling with dedication constraint. As described by previous research efforts, we can use two approaches to achieve high utilization of photo machines: 1) assignment of each lot for photo machines; and 2) flow control of dedicated lots. For the first category,

Kidambi developed a methodology based on the combination of earliest start date rule and least lots ahead rule to allocate lots in the first photo step. (Kidambi 2001). Shr et al. proposed a heuristic scheduling approach for achieving load balancing among identical photo machines (Shr et al. 2006; Shr et al. 2008). Pham et al. presented an integer linear program based framework to solve lot assignment problems with respect to dedication constraint (Pham et al. 2008). Klemmt and Weigert proposed a simulation based optimization approach for parallel machine problems with dedication constraint (Klemmt and Weigert 2011).

Studies that belong to the second category were focused on controlling the flow of dedicated lots. Wu et al. introduced a different approach to prevent the problems that may be caused by dedication constraint. They developed a release policy and dispatching rules to prevent load unbalance in conjunction with work-in-process (WIP) starvation of photo machines with dedication constraint (Wu et al. 2006; Wu et al. 2008(a); Wu et al. 2008(b)). Although there have been various studies on the subject of dedication constraint, the FAB still has significant challenges in achieving high utilization of photo machines.

This paper focuses on the first category regarding assignment of lots and proposes a dispatching rule to achieve high utilization of photo machines with dedication constraint. As states dynamically change in a FAB, a dispatching rule that adapts to these states is more likely to provide better results than a static dispatching rule (Sarin et al. 2011). To describe a manufacturing state at any given point in time, we introduce the concept of dedication load, which is defined as the sum of the workload for lots dedicated to each photo machine. By using dedication load, it is possible to achieve load balancing between identical photo machines. In the next section, we will address a detailed explanation of the proposed dispatching rule.

To conduct the simulation, we used the commercial software MOZART® developed by VMS solutions (Ko et al. 2013). The reminder of this paper is organized as follows. Section 2 provides a detailed explanation for the three boundary based state-dependent dispatching rule. The experimental results are analyzed in Section 3. Finally, concluding remarks are presented in Section 4.

2 DEDICATION LOAD BASED DISPATCHING RULE

This section provides a detailed explanation of the proposed dispatching rule. The photo steps can be classified into two types: 1) dedication mark step and 2) dedication step. Dedication mark step includes only the first photo step of each process. There only exists one dedication mark step for each process. The dedication step includes all photo steps except for the first photo step. When a photo machine processes a lot at the dedication mark step, it increases the dedication load of the photo machine. On the contrary, the dedication load of the photo machine is decreased by processing a lot at the dedication step. This means that the dedication load is changed whenever a photo machine performs dispatching. If the dedication load of photo machines is not managed properly, it may cause load unbalance of the photo machines. Thus, it is necessary to apply an algorithm to manage the dedication load of identical photo machines. The proposed dispatching rule determines the one of the two categories to achieve the load balancing of identical photo machines, whenever a photo machine becomes available.

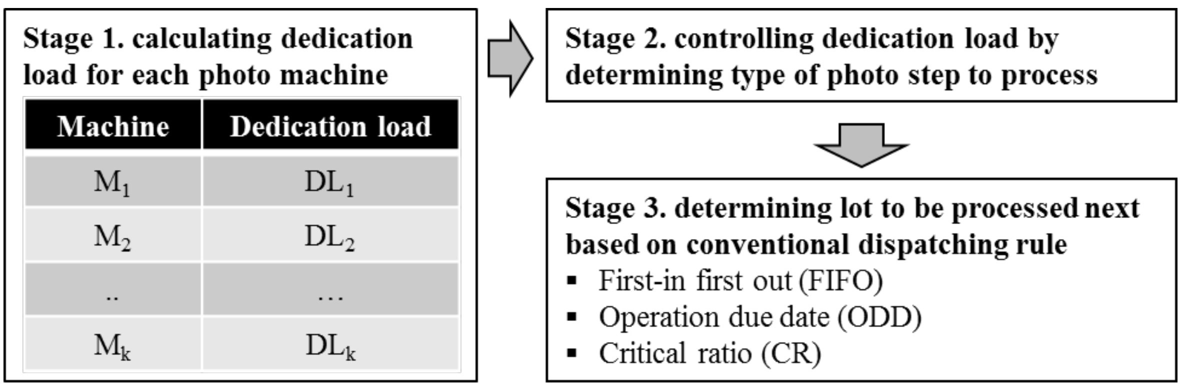


Figure 2: Overview of the proposed dispatching rule.

The main algorithm is presented first, and additional explanations are then provided. As shown in Figure 2, the main algorithm consists of three main stages. 1) calculation of dedication load for each photo machine, 2) control of dedication load for M_d (defined below) and 3) determination of lot to be processed next based on conventional dispatching rule. Although there are three main stages, this paper focuses on the first two stages. For a formal explanation of the proposed dispatching rule, we define several terms as follows:

- M_k: k^{th} photo machine.
- M_d: a photo machine that becomes available at current time.
- D-lots$_k$: lots available for dispatching of M_k at current time.
- Workload(i, M_k): the workload of M_k for lot i at current time.
- DL_k: the dedication load of M_K at current time.

For the first step, it is necessary to calculate the dedication loads of other identical photo machines as well as M_d. The dedication load of photo machine k can be computed by the following equation (1).

$$Dedication\ load_k = \sum_{i=1}^{n} \sum_{j=c}^{m} RePT_{ij} \qquad (1)$$

where n is the number of lots dedicated to machine k, c is an index of the next photo step of lot i, m is the number of remaining photo steps that lot i has to pass through to be completed, and $RePT_{ij}$ is the remaining processing time of lot i at step j. Figure 3 shows an example of a dedication load. Assuming that lots b, c, and d are dedicated to photo machine M_d, the dedication load of M_d equals the sum of

Workload(b, M_d), Workload(c, M_d), and Workload(d, M_d). A lot a could not be considered for the calculation of dedication load of M_d, as the lot was not yet dedicated to any M_k. Workload(c, M_d) is equal to Workload(d, M_d) as the remaining photo steps of lot c is the same with the lot d.

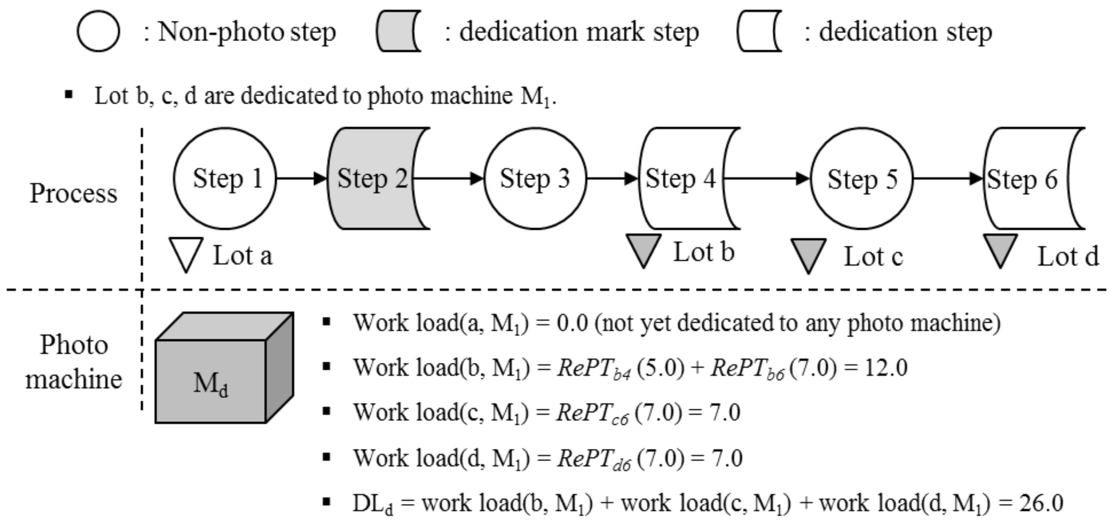


Figure 3: An example of dedication load for photo machine.

In the second stage, the proposed dispatching rule used an algorithm to determine the type of photo step to process. First, it was necessary to calculate the average dedication load for the photo machines (DL_{avg}). Subsequently, DL_d was compared with DL_{avg}. If DL_d was lower than DL_{avg}, the proposed dispatching rule returned lots at the dedication mark step. As the proposed dispatching rule determined the type of photo steps without considering lots for dispatching, it was necessary to check whether there existed a lot that could be processed. Assuming the algorithm selected the dedication mark step type, then it was necessary to consider lots at the dedication steps to avoid idle of the photo machines if there was not a lot at the dedication mark steps. The same was true for the case where the dedication step type was selected. The proposed dispatching rule achieved the load balancing of the photo machines by controlling the dedication load based on the three methods.

- **Stage 2. Control of dedication load**

```
Step 1) DL_avg = calculate the average of dedication loads for identical photo machines;
Step 2) If(DL_d < DL_avg)
            dedicType = dedication mark type;
        Else
            dedicType = dedication type;
Step 3) corr-lots = find lots at steps corresponding to dedicType;
Step 4) If(corr-lots is null)
            return D-lots_k;
        Else
            Return corr-lots;
```

The role of the previous stages was to determine the type of photo step to process. Next, it was necessary to determine a lot to be processed based on the lots determined in the previous stage. In the final stage, we employed a conventional dispatching rule that considered the required objective. For example, to achieve on-time delivery, it was necessary to apply the operation due date (ODD) dispatching rule.

3 EXPERIMENTAL RESULTS

To construct a modern FAB model, a reference model was required to select a common example of a FAB. As a reference model, this paper employed the wafer FAB dataset MIMAC6 from Measurement and Improvement of Manufacturing Capacities (MIMAC) (Fowler and Robinson 1995). However, the MIMAC dataset was developed a few decades ago; therefore, it is not enough to describe a modern FAB. To improve reality of FAB model, we modified the MIMAC dataset in terms of capacity, type of machines and quantity demanded. Table 1 shows the result of modification work in detail.

Table 1: Comparison of original MIMAC data and modified FAB model.

Modeling aspect	MIMAC6 model	Modified FAB model
Number of products (processes)	9	9
Number of tool groups	93	93
Number of tools	188	442
Wafers in a lot	24	24
Lots released per year	2777	8950
Number of tools per tool group	1-7	1-16
Machine types	Table, batch	Table, batch, inline
Raw processing time range (hours)	11-18	11-16
Total number of processing steps	2541	2541
Sequence dependent setup	Yes	Yes
Dedication constraint	No	Yes

The simulations were conducted for six months. The first four months were not consider as they represented the warm-up period. As performance measures to estimate dispatching rule, we used on-time delivery rate, average utilization of photo machines, and variance utilization of photo machines. For the simulation experiments of the proposed dispatching rule, we employed the MOZART® developed by VMS solutions.

To compare the performance of the proposed dispatching rule, it is necessary to design simulation experiments by using the three conventional dispatching rules (first-in first-out (FIFO), ODD, and critical ratio (CR)). For convenience, if FIFO rule is applied to the proposed dispatching rule, we refer to the proposed dispatching rule as ‘proposed rule (FIFO)’. ODD and CR are calculated in the following way:

- ODD = Due date – remaining cycle time.
- CR = Remaining cycle time / (Due date – now).

The experimental results are presented in Figures 4, 5 and 6. As shown in Figures 4 and 5, the load balancing of identical photo machines was directly related to utilization of the photo machines. Additionally, load balancing significantly affected the on-time delivery. The results indicated it was important to achieve the load balance for high performance of the FAB. To improve the load balance, we developed a dedication load based the dispatching rule. Figure 4 shows that the proposed dispatching rule was superior to the conventional dispatching rules with respect to the load balancing of photo machines.

As the load balance is improved, the utilization of photo machines and on-time delivery also are improved in the case of two conventional dispatching rules except for the FIFO rule. Under the proposed dispatching rule, we were able to improve the performance of the FAB.

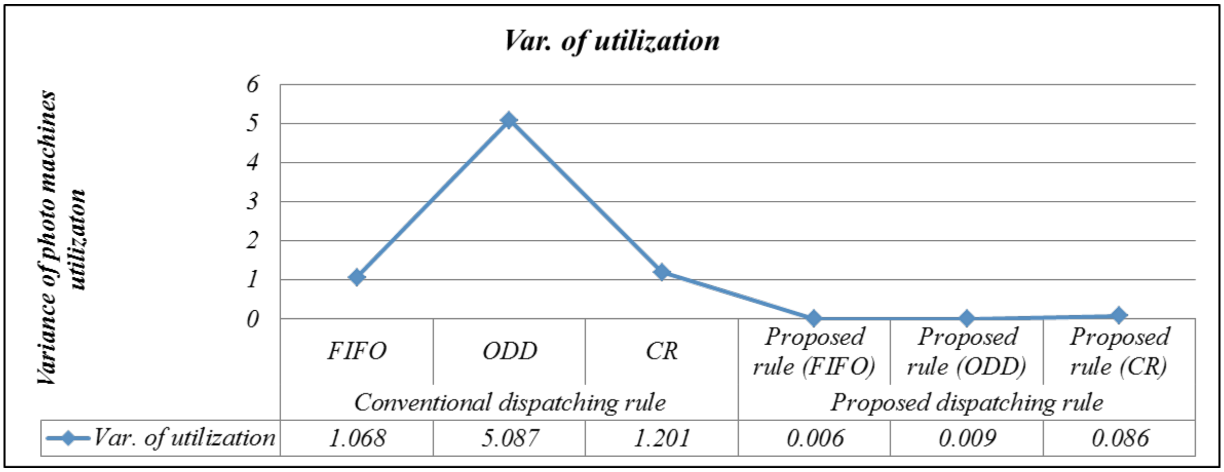


Figure 4: Variance of photo machine utilization.

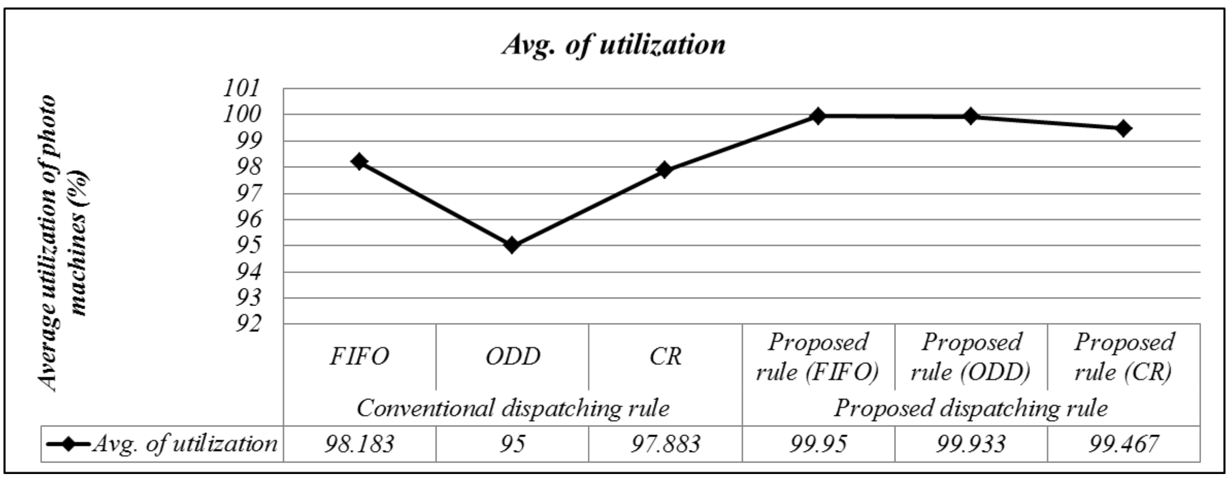


Figure 5: Average of photo machine utilization.

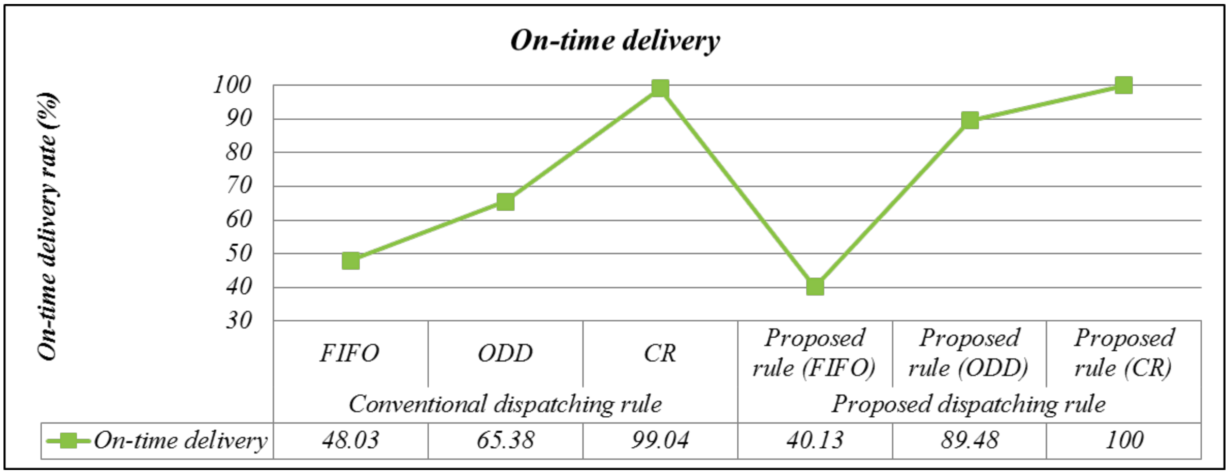


Figure 6: Percentage of on-time delivery.

4 SUMMARY

This paper addresses a multi-objective FAB scheduling problem with dedication constraint where a lot must be processed by same photo machine at all photo steps. Most of FABs have natural bias that significantly affects the alignment of patterns between different photo steps. The natural bias has a negative effect on quality and yield of products. To overcome the problem, the dedication constraint has been applied to photo machines that are considered as bottleneck. Although, the dedication constraint solves the natural bias, it may decrease the utilization of photo machines. Thus, it is important to perform scheduling for photo machines by considering dedication constraint.

In this paper, we proposed a dispatching rule to achieve the load balancing of photo machines in wafer FABs with dedication constraint. To achieve the load balance, we introduced the concept of dedication load. The proposed dispatching rule consists of three main stages: 1) calculation of dedication load for each photo machine. 2) control of dedication load for M_d, and 3) determination of the lot to be processed next based on conventional dispatching rules. Although there are three main stages, this paper focused on only the first two main stages.

To simulate the proposed dispatching rule, we used the commercial software MOZART® developed by VMS solutions and the FAB model constructed using MIMAC dataset 6. The FAB model was modified to reflect the nature of the real modern FAB. To prove the performance of the proposed dispatching rule, six dispatching rules were compared by simulation. Simulation results showed the proposed dispatching rule was superior to conventional dispatching rules with respect to the load balancing of the photo machines.

ACKNOWLEDGMENTS

This work was partially supported by the National Research Foundation grant [NRF-2015R1A2A2A01005871] funded by the Ministry of Education, Science and Technology, Korea. Also, the research was supported by the ICT R&D program of MSIP/IITP [R-20150505-000691, IoT-based CPS platform technology for the integration of virtual-real manufacturing facility].

REFERENCES

Akcalt, E., K. Nemoto, and R. Uzsoy. 2001. "Cycle-time Improvements for Photolithography Process in Semiconductor Manufacturing." *IEEE Transactions on Semiconductor Manufacturing* 14:48-56.

Andreas, K., and W. Gerald. 2011. "An Optimization Approach for Parallel Machine Problems with Dedication Constraints: Combining Simulation and Capacity Planning." In *Proceedings of the 2011 Winter Simulation Conference*, edited by S. Jain, R. R. Creasey, J. Himmelspach, K. P. White, and M. Fu, 1986-1998. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Fowler, J., and J. Robinson. 1995. "Measurement and Improvement of Manufacturing Capacities (MIMAC): Final Report." *Technical Report 95062861A-TR*, SEMATECH, Austin, TX.

Hiroyasu, T., I. Hiroaki, H. Hirotaka, and C. Takayuki. 2005. "Dynamic Load Balancing Among Multiple Fabrication Lines Through Estimation of Minimum Inter-Operation Time." *IEEE Transactions on Semiconductor Manufacturing* 18(1):202-213.

Huy, N. A., A. M. D. Shr, H. N. A. Pham, and P. P. Chen. 2008. "An Integer Linear Programming Approach for Dedicated Machine Constraint." In *Proceedings of the Seventh IEEE/ACIS International Conference on Computer and Information Science*, 69-74.

Johri, P. K. 1993. "Practical Issues in Scheduling and Dispatching in Semiconductor Wafer Fabrication." *Journal of Manufacturing Systems* 12:474-483.

Kidambi, M. R. 2001. "Impact of Lot Dedication on the Performance of the FAB." Master. Thesis, Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Kim, Y. D., J. U. Kim, S. K. Lim, and H. B. Jun. 1998. "Due-Date Based Scheduling and Control Policies in a Multiproduct Semiconductor Wafer Fabrication Facility." *IEEE Transactions on Semiconductor Manufacturing* 11(1):155-164.

Ko, K., B. H. Kim, and S. K. Yoo. 2013. "Simulation Based Planning & Scheduling System: MOZART®." In *Proceedings of the Winter Simulation Conference*, edited by R. Pasupathy, S.-H. Kim, A. Tolk, R. Hill, and M. E. Kuhl, 4103-4104. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Lin, J. T., F. K. Wang, and P. C. Kuo. 2005. "A Parameterized-Dispatching Rule for a Logic IC Sort in a Wafer Fabrication." *Production Planning & Control* 16(5):426-436.

Liu, A., A. M. D. Shr, and Y. Cheng. 2006. "A Fuzzy Scheduling System for Dedicated Machine Constraint." In *Proceedings of the 2006 Joint Conference on Information Sciences*, Kaohsiung, Taiwan.

Miwa, T., N. Nishihara, and K. Yamamoto. 2005. "Automated Stepper Load Balance Allocation System." *IEEE Transactions on Semiconductor Manufacturing* 18(4):510-516.

Mönch. L., M. Prause, and V. Schmalfuss. 2001. "Simulation-Based Solution of Load-Balancing Problems in the Photolithography Area of a Semiconductor Wafer Fabrication Facility." In *Proceedings of the 2001 Winter Simulation Conference*, 1170-1177. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Park, S. C., E. Ahn, Y. Chung, K. Yang, B. H. Kim, and J. C. Seo. 2013. "Fab Simulation with Recipe Arrangement of Tools." In *Proceedings of the 2013 Winter Simulation Conference*, edited by R. Pasupathy, S. H. Kim, A. Tolk, R. Hill, and M. E. Kuhl, 3840-3849. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Pham, H. N. A., A. M. D. Shr, and P. P. Chen. 2008. "An Integer Linear Programming Approach for Dedicated Machine Constraint." *International Conference on Computer and Information Science*, Washington DC, 69-74.

Sha, D. T., S. Y. Hsu, Z. H. Che, and C. H. Chen. 2006. "A Dispatching Rule for Photolithography Scheduling with an On-Line Rework Strategy." *Computers & Industrial Engineering* 50:233-247.

Shirley, J. T. 2011. "Bottleneck Management Strategies in Semiconductor Wafer Fabrication Facilities." In *Proceedings of the 2011 International Conference on Industrial Engineering and Operations Management*, 3-8. Kuala Lumpur, Malaysia.

Shr, A. M. D., A. Liu, and P. P. Chen. 2006. "A Heuristic Load Balancing Scheduling Approach for Dedicated Machine Constraint." In *Proceedings of the 19th International Conference on Industrial,* *Engineering & Other Applications of Applied Intelligent Systems(IEA/AIE'06)*, edited by M. Ali and R. Dapoigny, 750-759. Lecture Notes in Artificial Intelligence (LNAI) 4031, Springer-Verlag, Berlin Heidelberg.

Shr, A. M. D., A. Liu, and P. P. Chen. 2006. "A Load Balancing Scheduling Approach for Dedicated Machine Constraint." In *Proceedings of the 8th International Conference on Enterprise Information Systems ICEIS 2006*, 170-175. Paphos, Cyprus.

Shr, A. M. D., A. Liu, and P. P. Chen. 2006. "A Load Balancing Method for Dedicated Photolithography Machine Constraint." *Information Technology for Balanced Manufacturing Systems* 220:339-348.

Shr, A. M. D., A. Liu, and P. P. Chen. 2008. "Load Balancing Among Photolithography Machines in the Semiconductor Manufacturing System." *Journal of Information Science and Engineering* 24:379-391.

Uzsoy R., L. K. Church, and I. M. Ovacik. 1992. "Dispatching Rules for Semiconductor Testing Operations: a Computational Study." In *Proceedings of the thirteenth IEEE/CHMT International Electronics Manufacturing Technology Symposium*, 272-276.

Wu, M. C., Y. L. Huang, Y. C. Chang, and K. F. Yang. 2006. "Dispatching in Semiconductor FABs with Dedication Features." *International Journal of Advanced Manufacturing Technology* 28:978-984.

Wu, M. C., S. Chiou, and C. Chen. 2008. "Dispatching for Make-to-order Wafer Fabs with Dedication and Mask Set-up Characteristics." *International Journal of Production Research* 46:3993-4009.

Wu, M. C., J. Jiang, and W. Chang. 2008. "Scheduling a Hybrid MTO/MTS Semiconductor Fab with Dedication Features." *International Journal of Production Economics* 112:416-426.

Yang, J. H. 2015. "Minimizing Total Completion Time in a Two-stage Hybrid Flow Shop with Dedicated Machines at the First Stage." *Computers and Operations Research* 58:1-8.

AUTHOR BIOGRAPHIES

YONG H. CHUNG received a bachelor degree (2011) in industrial and information system engineering and a master degree (2013) in industrial engineering, Ajou University, Korea. He is now a Ph. D candidate in industrial engineering, Ajou University, Korea. He is interested in simulation-based scheduling and planning, digital manufacturing, and mesh simplification. His email address is yongho1230@gmail.com.

KANG H. CHO received a bachelor degree (2013) in industrial and information system engineering and a master degree (2015) in industrial engineering, Ajou University, Korea. He is now a Ph. D candidate in industrial engineering, Ajou University, Korea. He is interested in simulation-based scheduling and planning, virtual manufacturing, and image pattern recognition. His email address is sung15jin@gmail.com.

BYUNG H. KIM is the president of VMS Solutions Co., Ltd. since 2000. He received a BS from Sungkyunkwan University in 1993, a MS from KAIST in 1995, and a Ph.D. from KAIST in 2001, all in Industrial Engineering. His main interests are simulation-based scheduling and planning, manufacturing information systems, BPMS, and virtual manufacturing. His email address is kbhee@vms-solutions.com.

SANG C. PARK was granted his bachelor (1994), master (1996) and Ph.D. (2000) degrees in industrial engineering, Korea Advanced Institute of Science and Technology (KAIST). He is a professor in Dept. of IE, Ajou University, Korea, since 2004. He is interested in modeling and simulation (M&S), combat simulation for defense, and digital manufacturing system. His email address is scpark@ajou.ac.kr.