

조항민* · 정인재*,[†]

*한양대학교 산업공학과
[†]한양대학교 기술경영전문대학원

Preemptive Goal Programming Based Heuristic Methods for Reentrant Flow Shop Planning with Bi-Objective

Hang-Min Cho* · In-Jae Jeong*,[†]

*Department of Industrial Engineering, Hanyang University

[†]Graduate School of Technology and Innovation Management, Hanyang University

이 논문은 병렬 설비로 이루어진 다수의 단계를 포함하는 재방문이 있는 혼합흐름공정의 계획 문제를 다룬다. 재방문작업에서 제품은 몇몇 공정을 여러 번 방문하게 되고 이로 인하여 재공의 혼잡과 장비의 유희의 원인이 된다. 이 상황에서는 생산성과 고객 만족도를 향상 시키는 것이 중요한 이슈이다. 따라서 본 논문은 혼합흐름공정에서 스루풋을 최대화하고 지연된 고객 수요를 최소화하기 위해 우선순위 목표계획법 기반의 휴리스틱 방법들을 제안한다. 그리고 이 휴리스틱 방법은 이전 문헌에서 제시된 방법과 비교하여 성능을 비교하였다.

Keywords : Bi-Objective, Reentrant Operation, Flow shop

1. Introduction

This paper considers production planning in the context of hybrid flow shops. The flow shop has serial stages where each stage consists of identical parallel machines. Products can be processed at any one of the parallel machines at a stage in the hybrid flow shop. Also a product may have reentrant operations which require revisits of some stages several times. This may cause the congestion of work in process (WIP) or equipment idleness. In the real world, a configuration of the reentrant hybrid flow shop may be found in electronics industry such as printed circuit board (PCB), sem-

iconductor wafer fabrication and thin film transistor and liquid crystal display (TFT-LCD) manufacturing [3, 12, 15]. In addition, TFT process in TFT-LCD manufacturing are quite similar to wafer fabrication in semiconductor manufacturing [10, 12, 17, 24]. The reentrant operations are required when glasses or wafers undergo multiple layer processes of photolithography in TFT or fabrication line. The progress of each layer has the steps to be consisted of photolithography, etching, thin filming, diffusion, and so on. The photolithography has usually the serial processes, which is coating, stripping, exposing, and developing [10].

The reentrant hybrid flow shop planning has been re-

searched mostly in environments of semiconductor wafer fabrication and TFT-LCD manufacturing. There are a number of studies of dispatching rules for operational control on wafer fabrication in the literature (see Sarin et al. [22], for detail survey). Spearman et al. [23] suggested the CONWIP method which is a controlling WIP policy to be simultaneously managed both WIP and throughput, and they compared to pull system in the hybrid flow shop environment. For reentrant hybrid flow shop problem in semiconductor wafer fabrication, Ehteshami et al. [4] studied controlling the WIP to reduce the cycle time, and Lee et al. [14] studied an input policy and WIP control policy considering dynamic cycle time. Lin and Lee [16] proposed a queueing network-based algorithm estimating a WIP level to achieve target throughput rate with a reasonable cycle. Rose [20, 21] proposed a simulation model to estimate of the cycle time distribution of semiconductor wafer factories. Robinson and Chance [19] suggested a methodology for wafer fab cycle time management using the actual manufacturing execution system (MES). The mean value analysis based an approximation method is investigated by Park et al. [18]. The approximation method is simple rule for estimating the mean cycle of each class of jobs, the mean queue length of buffer and the throughput of reentrant line with batch machine and multi-class jobs.

For bottleneck stage on reentrant hybrid flow shop, Kim et al. [8, 9] and Yea [25] suggested how to determine the target WIP level using the fab balanced in semiconductor wafer fabrication. Also they suggested the mixed integer programming model and the heuristic methods for shift scheduling to achieve the production target, which are stepper allocation to reduce the difference between actual WIP level and target WIP level. Lee et al. [13] suggested the dispatching rules to drive the target production and the target WIP for the input and bottleneck scheduling rules for production and cycle time reduction in semiconductor fabrication line. Lee and Kim [11] suggested the balance control policy for bottleneck scheduling and operation management in the fabrication line. There showed how to determine the proper WIP level, and measure the balance using the proper WIP level. There also proposed the optimization model applying the balance measurement for production and cycle time reduction. Lee and Lee [12] defined the managing point as bottleneck process step and suggested three mathematical models in TFT-LCD fabrication manufacturing. The models are the throughput driven push model, the balance driven push-pull model using the WIP controlling policy, and the target driven pull model

using incapacitated production target projection applying the cycle time required. Kang and Lee [7] suggested the due date based optimization models for make-to-order semiconductor industry, that are the target control model, the movement control model and the WIP control model. Lee et al. [10] suggested the target balance (TB) optimization models using production target, due-date, and WIP in semiconductor fabrications. Also their models were tested on multi-stage with bottleneck processes in TFT-LCD fabrication.

Gupta et al. [5] surveyed current researches for operational planning and control problem in semiconductor wafer production. There were various aspects that the productivity is related throughput, utilization, workload balance and so on, and the customer satisfaction is related cycle time, demand, due date and so on. However most of the existing literature has investigated a single objective function or multi-objective functions that are not directly pursued but implicitly for the hybrid flow shop planning problem. This paper tries to explicitly deal the bi-objective function that are, productivity and customer satisfaction. We propose heuristic methods based on mathematical model to maximize throughput for productivity and to minimize delayed customer demand for customer satisfaction.

This paper is organized as follow : in section 2, we propose detailed problem description. Section 3 presents the procedure of the proposed heuristic methods. The comparison with TB model [10] for simulated data is shown in section 4. Section 5 concludes the paper with possible extension in the future.

2. Problem Description

This paper considers the multi-stages reentrant hybrid flow shop problem. The flow shop has serial stages, where each stage consists of identical parallel machines. Each product can visit several stages following the given product route in the hybrid flow shop. Moreover, products can revisit the some stages several times, this is a reentrant operation. We consider the stages as bottleneck processes that must be managed. Thus, this paper is focused on the operational planning for processing steps of the bottleneck stages as managing points among entire processing steps [3, 12]. It is assumed that the processing or staying on non-bottleneck stages between bottleneck stages takes one period time. Also the machines at each stage are assumed to be aggregated and processing times are given.

To describe the problem formally, a linear programming (LP) model with bi-objective is presented. Note that our model is a modified formulation of Kang and Lee [7], Lee et al. [10] and Lee and Lee [12] where they proposed the hybrid flow shop with bottleneck processes. Consider the following notations:

i	index for products, $i = 1, \dots, n$
j	index for operations of bottleneck stages in entire process
l	index for bottleneck stages, $l = 1, \dots, L$
t, t'	index for planning time periods, $t, t' = 1, \dots, T$
$D_{i,t}$	demand quantity of product i during time t
N_i	number of operations in bottleneck stages required for product i , $i = 1, \dots, n$
$p_{i,j}$	processing time of operation j of product i , $i = 1, \dots, n$ and $j = 1, \dots, N_i$
$S_{i,j}$	stage required for operation j of product i , $i = 1, \dots, n$ and $j = 1, \dots, N_i$
$WT_{l,t}$	total working time at stage l during time t
$IWIP_{i,j}$	initial WIP amount waiting to process operation j of product i
$INPUT_i$	raw material amount of product i

Decision variables

$X_{i,j,l,t}$	production amount of operation j of product i to be processed at stage l during time t
$WIP_{i,j,t}$	WIP amount waiting to process operation j of product i during time t
$V_{i,t}$	delayed customer demand of product i during time t
$Q_{i,t}$	throughput of product i during time t

Objective functions

$$\text{Minimize } \sum_{i=1}^n \sum_{t=1}^T V_{i,t} \quad (1)$$

$$\text{Maximize } \sum_{i=1}^n \sum_{t=1}^T Q_{i,t} \quad (2)$$

Subject to

$$WIP_{i,1,1} = IWIP_{i,1} - X_{i,1,S_{i,1},1} + INPUT_i \quad (3)$$

for $\forall i$

$$WIP_{i,j,1} = IWIP_{i,j} - X_{i,j,S_{i,j},1} \quad (4)$$

for $\forall i, j = 2, \dots, N_i$

$$WIP_{i,1,t} = WIP_{i,1,t-1} - X_{i,1,S_{i,1},t} + INPUT_i \quad (5)$$

for $\forall i, t = 2, \dots, T$

$$WIP_{i,j,t} = WIP_{i,j,t-1} - X_{i,j,S_{i,j},t} + X_{i,j-1,S_{i,j-1},t-1} \quad (6)$$

for $\forall i, j = 2, \dots, N_i, t = 2, \dots, T$

$$X_{i,j,S_{i,j},1} \leq IWIP_{i,j} \quad (7)$$

for $\forall i, j$

$$X_{i,j,S_{i,j},t} \leq WIP_{i,j,t-1} \quad (8)$$

for $\forall i, j, t = 2, \dots, T$

$$\sum_{i=1}^n \sum_{j=1}^{N_i} X_{i,j,l,t} p_{i,j} \leq WT_{l,t} \quad (9)$$

for $\forall l, t$

$$X_{i,N_i,S_{i,N_i},t} = Q_{i,t} \quad (10)$$

for $\forall i, t$

$$\sum_{t=1}^t X_{i,N_i,S_{i,N_i},t'} + V_{i,t} \geq \sum_{t'=1}^t D_{i,t'} \quad (11)$$

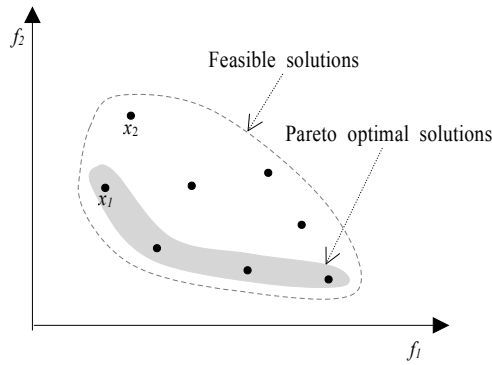
for $\forall i, t$

$$WIP_{i,j,t} \geq 0, X_{i,j,l,t} \geq 0, Q_{i,t} \geq 0, V_{i,t} \geq 0 \quad (12)$$

for $\forall i, j, l, t$

The bi-objective function is composed of simultaneously minimizing the sum of delayed customer demand in (1) and maximizing the sum of throughput in (2), where the throughput is specified in constraint (10), and the delayed customer demand is specified in constraint (11). At the end of each time period, the WIP balance equations are shown (3) through (6). Constraint (7) shows that the production amount cannot exceed the residing WIP on the first time period. Constraint (8) shows that the production amount can not exceed the residing WIP from second time period. Constraint (9) shows that the total working time of stage with aggregation machine is restricted by the available working time. Constraints (10) and (11) are the constraint of the throughput and the delayed customer demand, respectively. The throughput is the output at the last operation of each product. The delayed customer demand is the difference between cumulative sum of the throughput and demand values from the first time period to the current time period. Constraint (12) is the non-negativity restrictions of the variables.

Multi-objectives problems are commonly related to the Pareto optimal solution. The Pareto optimal solution is defined as follows; a solution x^* is Pareto optimal if no objective function can be improved by degrading at least one other objective functions [1]. As shown in <Figure 1>, a feasible solution x_2 is dominated by a feasible solution x_1 for bi-objective functions f_1 and f_2 . But the x_1 is non-dominated by other feasible solutions for anyone, and then the x_1 is Pareto optimal solution. In general, it is difficult to find all possible the Pareto optimal solutions for multi-objectives problems, this paper focuses on the method using the goal programming which is efficient and fast algorithm for multi-objectives problem.



<Figure 1> Example of Bi-Objective Problem

3. Solution Approach

In this section, we propose preemptive goal programming [2, 6] based algorithms. In preemptive goal programming, we define priority of objective function. In the first step, we optimize the problem based on the first objective. In the second step, we consider the second objective function such that the first optimal objective function value is not violated. The procedure continues until we consider all the objective functions. In this paper, we propose two heuristics. In heuristic (1), the first priority objective is the delayed customer demand and the second priority objective is the throughput. For the heuristic (2), we consider the throughput as the first priority objective and the delayed customer demand as the second priority objective.

Let Z^{de} and Z^{th} be the objective function of the delayed customer demand and the throughput, respectively. Also let z^{de} and z^{th} be the objective value of the delayed customer demand and the throughput, respectively. Then, structure of heuristic (1) is as following:

Heuristic (1)

Phase I. Optimize to minimize Z^{de} in LP as following:

$$\text{Minimize } Z^{de} = \sum_{i=1}^n \sum_{t=1}^T V_{i,t}$$

Subject to

$$(3), (4), (5), (6), (7), (8), (9), (11)$$

$$WIP_{i,j,t} \geq 0, X_{i,j,l,t} \geq 0, V_{i,t} \geq 0 \text{ for } \forall i, j, l, t$$

Phase II. Add constraint (13) for z^{de} and optimize to maximize Z^{th} in LP as following:

$$\text{Maximize } Z^{th} = \sum_{i=1}^n \sum_{t=1}^T Q_{i,t}$$

$$\text{Subject to } \sum_{i=1}^n \sum_{t=1}^T V_{i,t} \leq z^{de} \tag{3}$$

$$(3), (4), (5), (6), (7), (8), (9), (10), (11)$$

$$WIP_{i,j,t} \geq 0, X_{i,j,l,t} \geq 0, Q_{i,t} \geq 0, V_{i,t} \geq 0 \text{ for } \forall i, j, l, t$$

□

where constraint (13) shows that the delayed customer demand is restricted to z^{de} in phase I of heuristic (1).

Structure of heuristic (2) is as following:

Heuristic (2)

Phase I. Optimize to maximize Z^{th} in LP as following:

$$\text{Maximize } Z^{th} = \sum_{i=1}^n \sum_{t=1}^T Q_{i,t}$$

Subject to

$$(3), (4), (5), (6), (7), (8), (9), (10)$$

$$WIP_{i,j,t} \geq 0, X_{i,j,l,t} \geq 0, Q_{i,t} \geq 0 \text{ for } \forall i, j, l, t$$

Phase II. Add constraint (14) for z^{th} and optimize to minimize Z^{de} in LP as following:

$$\text{Minimize } Z^{de} = \sum_{i=1}^n \sum_{t=1}^T V_{i,t}$$

$$\text{Subject to } \sum_{i=1}^n \sum_{t=1}^T Q_{i,t} \geq z^{th} \tag{14}$$

$$(3), (4), (5), (6), (7), (8), (9), (10), (11)$$

$$WIP_{i,j,t} \geq 0, X_{i,j,l,t} \geq 0, Q_{i,t} \geq 0, V_{i,t} \geq 0 \text{ for } \forall i, j, l, t$$

□

where constraint (14) shows that the throughput is restricted to z^{th} in phase I of heuristic (2).

4. Experiments

This section describes the experiments that have been conducted to compare the results of the proposed algorithm and Lee et al. [10]'s TB models. The TB models use the incapacitated production target (IPT) which is the production target on each layer to be estimated using the product due date information, not considering the machine capacity. The TB-D model tries to minimize the difference between cumulative sum of the WIP and IPT from the last layer to current layer. The TB-R model tries to minimize the maximum value of TB, which is calculated from the cumulative sum of the

WIP from the last layer to current layer divided by the cumulative sum of IPT from the last layer to current layer.

The solutions were found using CPLEX 11.0 with Microsoft visual C++ 2005 language. The tests are performed on a personal computer with Intel(R) Core(TM)2 Duo CPU E8500 @ 3.16GHz 3.17GHz and DDR2 3.25G RAM. In this experiment, we set test problems based on the problems of Lee et al. [10] as collected from the historical database. The TFT-LCD fabrication line consist of a number of serial stages, however, the bottleneck stages is assumed to be the deposition, the photo and the PR strips stages in every stages, where machine of each stage are aggregated machine.

The TFT-LCD manufacturing is assumed that there is daily demand to produce 1500 glasses per day on average for a month, but test problems are formed a total of 60 periods for 10 days, each day is consisted of 6 periods, i.e. a planning decision time period is 4 hours. The number of product is 5 products, and the number of layer for each product is randomly generated in the range of discrete uniform distribution $DU[3, 5]$. Each bottleneck stage has 5 deposition machines, 10 steppers as photo machines and 5 PR strip machines, where their manufacturing cycle times are randomly generated in the range of continuous uniform distribution $U[5.64, 10.36]$ hours. The processing time on aggregated

machine to process each step depending on the layers for deposition and PR strip stages is randomly generated in the range of $U[0.30, 0.48]$ minutes. And the processing time on aggregated machine for photo stage is $U[0.15, 0.24]$ minutes.

The period demand of a product is calculated from the daily demand divided by 6. It is assumed that input volume is the average period demand. The working time in each period is set 220 minutes for each machine with the exception of 20 minutes for equipment loss time, which are setup, inspection, maintenance, machine breakdown, etc. Initial WIP for each period is assumed using average target WIP divided 6. The average target WIP is calculated by modifying the method in Kim et al. [8] and Yea [25] as following:

$$\begin{aligned} & \{\text{average target WIP}\} \\ & = ((\{\text{average daily demand}\}/2)/4) \times \{\text{cycle time}\} \quad (16) \end{aligned}$$

We consider three different types of initial WIP: 1.0 times, 1.5 times and 2.0 times of average target WIP. Also, we consider three variations of daily demand: In the type 1, the daily demand for each product is 300. In the type 2, the daily demand is generated in the range of $DU[240, 360]$ for each product with 20% variation. In the type 3, the daily demand for each product is generated in the range of $DU[120, 480]$ with 60% variation.

<Table 1> The Result of the Delayed Customer Demand and the Throughput for Problems

Initial WIP	Demand	TB-D		TB-R		Heuristic (1)		Heuristic (2)		
		Z^{le}	Z^h	Z^{le}	Z^h	Z^{le}	Z^h	Z^{le}	Z^h	
1.0 times	Type 1	Avg.	4345	169	3026	179	2667	173	2876	187
		Min	3270	129	2001	144	1804	136	1849	152
		Max	5571	203	4289	208	3586	208	4250	221
	Type 2	Avg.	4328	168	3113	177	2759	171	2983	184
		Min	3416	140	2303	142	2002	136	2140	151
		Max	5192	205	3907	212	3592	208	4189	223
	Type 3	Avg.	4466	163	3162	174	2807	170	2996	183
		Min	3284	140	2084	142	1948	140	1969	156
		Max	5492	199	4175	202	3742	203	3792	213
1.5 times	Type 1	Avg.	3647	183	2409	190	1966	185	2211	200
		Min	2521	143	1351	156	996	148	1137	165
		Max	4911	217	3721	226	2957	224	3623	235
	Type 2	Avg.	3683	182	2520	188	2089	182	2340	196
		Min	2782	152	1525	152	1220	147	1360	163
		Max	4639	220	3388	226	2964	222	3487	238
	Type 3	Avg.	3814	176	2598	184	2149	182	2340	195
		Min	2578	152	1452	155	1230	152	1250	166
		Max	4888	213	3869	213	3163	215	3273	227
2.0 times	Type 1	Avg.	2910	197	1993	199	1461	195	1711	210
		Min	1772	158	948	166	346	158	688	176
		Max	4147	231	3599	243	2449	239	3024	249
	Type 2	Avg.	3005	194	2015	196	1577	193	1831	207
		Min	2013	164	964	163	685	158	786	175
		Max	4011	235	2782	236	2389	233	2973	247
	Type 3	Avg.	3153	188	2213	193	1673	192	1895	205
		Min	1800	162	1080	167	805	159	825	174
		Max	4165	225	3333	226	2702	226	3038	235

For each case of the initial WIP and demand, 20 random problems are generated and tested. <Table 1> shows the result of average period values of the delayed customer demand (Z^{de}) and the throughput (Z^{th}) for problems, where TB-D and TB-R are the model of Lee et al. [10]'s TB models. It seems that the performance of heuristic (1) and heuristic (2) are different according to first priority objective. For the delayed customer demand, heuristic (1) is better than heuristic (2). For the throughput, heuristic (2) is better than heuristic (1). Also, the result of heuristic (1) and heuristic (2) are significantly better than TB models for every problem on the delayed customer demand. Also the result of heuristic (1), heuristic (2) and TB-R model are slightly better than TB-D model for the every problem on the throughput. In conclusion, the proposed algorithms are more effective in terms of customer satisfaction in addition to productivity.

<Table 2> shows the computation time of algorithms for problems. It seems that the proposed algorithms are needed a slightly less computational time than the TB models.

<Table 2> The Average Computational Time for Problems(sec.)

Initial WIP	Demand	TB-D	TB-R	Heuristic (1)	Heuristic (2)
1.0 times	Type 1	8.99	9.33	8.34	6.53
	Type 2	8.85	8.15	7.32	6.25
	Type 3	11.71	9.77	7.75	7.67
1.5 times	Type 1	9.54	9.68	8.46	6.99
	Type 2	8.85	8.98	7.3	5.94
	Type 3	12.94	11.04	7.93	6.97
2.0 times	Type 1	9.95	10.45	7.38	6.34
	Type 2	8.99	10.38	7.07	6.02
	Type 3	13.55	9.82	7.11	6.68

5. Conclusion

The performance of reentrant hybrid flow shop is closely considered several objectives related to productivity and customer satisfaction in real world situations. We propose preemptive goal programming based algorithms. The proposed algorithms perform better than existing TB models managing WIP based on due date in terms of the throughput and the delayed customer demand.

This research can be extended to multi-objective function problems for real world scenarios.

References

- [1] Baykasoglu, A., Owen, S., and Gindy, N.; "A taboo search based approach to find the Pareto optimal set in multiple objective optimization," *Engineering Optimization*, 31 : 731-748, 1999.
- [2] Charnes, A. and Cooper W. W.; *Management model and industrial application of linear programming*, John Wiley and Sons, New York, 1961.
- [3] Cho, H. M., Bae, S. J., Kim, J., and Jeong, I. J.; "Bi-objective scheduling for reentrant hybrid flow shop using Pareto genetic algorithm," *Computer and Industrial Engineering*, 61 : 529-541, 2011.
- [4] Ehteshami, B., Pétrakian, R. G., and Shabe, P. M.; "Tradeoffs in cycle time management: hot lots," *IEEE Transactions on Semiconductor Manufacturing*, 5(2) : 101-106, 1992.
- [5] Gupta, J. N. D., Ruiz, R., Folwer, J. W., and Mason, S. J.; "Operational planning and control of semiconductor wafer production," *Production Planning and Control*, 17(7) : 639-647, 2006.
- [6] Ignizio, J. P.; "A review of goal programming: A tool for multi objective analysis," *Journal of Operational Research Society*, 29(11) : 1109-1119, 1978.
- [7] Kang, H. H. and Lee, T. H.; "Make-to-order scheduling in foundry semiconductor fabrication," *International Journal of Production Research*, 45(3) : 615-630, 2007.
- [8] Kim, S., Yea, S., and Kim, B.; "Stepper scheduling in semiconductor wafer fabrication process," *Proceedings of the International Conference on Modeling and Analysis of Semiconductor Manufacturing*, Arizona, 157-162, 2000.
- [9] Kim, S., Yea, S. H., and Kim, B.; "Shift scheduling for steppers in the semiconductor wafer fabrication process," *IIE Transactions*, 34 : 167-177, 2002.
- [10] Lee, B., Lee, T. H., Yang, T., and Ignisio, J.; "A due-date based production control policy using WIP balance for implementation in semiconductor fabrications," *International Journal of Production Research*, 46(20) : 5515-5529, 2008.
- [11] Lee, Y. H. and Kim, T.; "Manufacturing cycle time reduction using balance control in the semiconductor fabrication line," *Production Planning and Control*, 13(6) : 529-540, 2002.
- [12] Lee, Y. H. and Lee, B.; "Push-pull production planning of the reentrant process," *International Journal of Advanced Manufacturing Technology*, 22 : 922-931, 2003.
- [13] Lee, Y. H., Park, J. K., and Kim, S. Y.; "Experimental study on input and bottleneck scheduling for a semi-

- conductor fabrication line,” *IIE Transactions*, 34 : 179-190, 2002.
- [14] Lee, Y., Kim, S., Yea S., and Kim, B.; “Production planning in semiconductor wafer fab considering variable cycle times,” *Computer and Industrial Engineering*, 33 : 713-716, 1997.
- [15] Linn, R. and Zhang, W.; “Hybrid flow shop scheduling: a survey,” *Computers and Industrial Engineering*, 37 : 57-61, 1999.
- [16] Lin, Y. H. and Lee, C. E.; “A total standard WIP estimation method wafer fabrication,” *European Journal of Operation research*, 131 : 78-94, 2001.
- [17] Lu, S. C. H., Ramaswamy, D., and Kumar, P. R.; “Efficient scheduling policies to reduce mean and variance of cycle-time in semiconductor manufacturing plants,” *IEEE Transactions semiconductor manufacturing*, 7(3) : 374-388, 1994.
- [18] Park, Y., Kim, S., and Jun, C. H.; “Mean value analysis of reentrant line with batch machines and multi-class jobs,” *Computers and Operations Research*, 29 : 1009-1024, 2002.
- [19] Robinson, J. and Chance, F.; “Wafer fab cycle time management using MES data,” *Proceedings of the International Conference on Modeling and Analysis of Semiconductor Manufacturing*, Arizona, 183-187, 2000.
- [20] Rose, O.; “Estimation of the cycle time distribution of a wafer fab by a simple simulation model,” *Proceedings of the International Conference on Semiconductor Manufacturing Operational Modeling and Simulation*, San Francisco, 133-138, 1999.
- [21] Rose, O.; “Improved simple simulation models for semiconductor wafer factories,” *Proceedings of the Winter Simulation Conference*, Washington, D.C., 1708-1712, 2007.
- [22] Sarin, S. C., Varadarajan, A., and Wang, L.; “A survey of dispatching rules for operational control in wafer fabrication,” *Production planning and Control*, 22(1) : 4-24, 2011.
- [23] Spearman, M. L., Woodruff, M. L., and Hopp, W. J.; “CONWIP: a pull alternative to kanban,” *International Journal of Production Research*, 28(5) : 879-894, 1990.
- [24] Vargas-Villamil, F. D. Rivera, D. E., and Kempf, K. G.; “A hierarchical approach to production control of reentrant semiconductor manufacturing lines,” *IEEE Transactions on Control Systems Technology*, 11(4) : 578-587, 2003.
- [25] Yea, S. H.; “A shift scheduling in semiconductor wafer fabrication,” M. S. Dissertation, Pohang University, Korea, 1997.