Journal of Intelligent Manufacturing, 15, 233–244, 2004

Feasibility study of modular plant for 300 mm-IC fabrications

SUHUA HSIEH and CHUNG-RUNG HUNG

Department of Mechanical Engineering, National Taiwan University, Republic of China

Received June 2002 and accepted March 2003

In semiconductor manufacturing, long fabrication construction time, high probability of equipment failures, and long repair time significantly increase the time to bring a new device to market, subsequently reducing the competitiveness of products. By the advent of production 300 mm wafers, automation is imperative because of the need to reduce capital and operating costs. To solve these problems, Industrial Technology Research Institute (ITRI) of Taiwan proposed a conceptual modular 300 mm-IC fabrication facility. This study investigates the feasibility of this concept. The following issues are examined. First, can a modular plant maintain reasonable productivity with high equipment failure rate and long repair time? Second, does a modular plant require more equipments than a traditional one? Third, how should a modular plant be laid out? Simulations are used to compare the performance of a modular plant with that of a traditional plant. Three different modular plant layouts, namely function-type, flow-line and process-layer, are constructed and compared. Simulation results demonstrate the advantages and drawbacks of a modular plant, thus clarifying the feasibility of adopting a modular plant for 300 mm.

Keywords: A modular plant, factory layout, production cycle times, mean time between failures, mean time to repair

1. Introduction

The manufacturing cost of integrated circuits (IC) has been falling at a rate of 50% every three years for the last several decades. Taiwan's IC industry faces three major problems—long plant construction time, low equipment effectiveness, and the advent of production 300 mm wafers.

The lifetime of IC products is comparatively short. An IC plant is usually designed for a limited range of products. In general, the construction of an IC plant divides into two phases, the construction of the building and the installation of equipments and utility/exhaust/air-conditioning piping systems. Therefore, if the plant construction time can be halved, product competitiveness is of course enhanced.

Equipment breakdown and long repair time reduce equipment effectiveness and cause rescheduling or serious management problems. Due to lack of professional IC equipment maintenance techniques in Taiwan, equipment breaks down frequently and repair times are long. This situation reduces the productivity of Taiwan's IC industry. However, productivity will not be affected at all if the broken equipment is removed immediately and repaired off line, and a working one is put in its place.

The move to 300 mm wafers is to maximize the productivity of a wafer fabrication. Recent research has turned to 300 mm generation wafer fabrication facilities design or/and automated material handling system (AMHS) design. Weiss (1996) pointed out that automation is imperative because of the need to reduce capital and operating costs, especially as fabrications ramp up to process larger diameter wafers. Factory layout is one of important issues for 300 mm fabrications. Industrial practice is dominated by a spine or perimeter process-layout factory design. Pierce and Stafford (1994) have compared these two designs and a custom design, and concluded that the spine layout is better than the other two. Peters and Taho (1997) investigated the spine and perimeter layouts and material handling system design integration problem and propose a methodology for solving this integrated design problem. Christopher *et al.* (1997) examined the performance of a number of different layouts under different conditions. Kurosaki *et al.* (1997) and Schroeder (1997) proposed automation-centric layouts with AMHS for 300 mm fabrications. Weiss (1997) has quantified the effects that material handling has on the cost of front-end wafer fabrication by analyzing the effects that layout and automation techniques have on footprint, fabrication costs and the manufacturing lead-time of a chip. Plata (1997) also identified 300 mm issues that affect the design of the factory from the individual machine to the overall concept. He concluded the factory design must accommodate future requirements and a new set of facility design requirements may prompt a re-look at the entire factory plan. Pillai *et al.* (1999) addressed Intel's 300 mm factory integration effort aimed at cross-functional optimization of fabrication layouts, AMHS and operations. Jefferson and Willbrandt (1999) stated that intra-bay automation increases process equipment utilization and reduces the labor required. Regardless of the contributions of previous research, there are few regarding solving the problems of long plant construction time and low equipment effectiveness for new 300 mm fabrications.

Industrial Technology Research Institute (ITRI) of Taiwan (Wu and Chiang, 1995; Wu *et al.*, 1998) proposed a conceptual modular IC fabrication plant for solving the above-mentioned problems. Unlike the construction of a traditional plant, the construction of the building and the installation of equipment and utility/exhaust/air-conditioning piping systems of a modular plant progress simultaneously at different places. Such progress is attributed to that equipment is installed in production modules. Various production modules are then located within the building individually by using a crane installed in the center of the building. The plant construction time is therefore cut in half. Moreover, when the plant begins operating, once equipment in a production module breaks down, instead of repairing the equipment, the crane removes the module containing the broken one and inserts a new module. An AMHS is installed in the system. By so doing, the aforementioned problems can be solved effectively.

This study investigates the feasibility of this idea. In particular, the following issues are addressed. First, can a modular plant maintain reasonable productivity with high equipment failure rate and long repair time? Second, does a modular plant require more equipments than a traditional one? Third, how should a modular plant be laid out? Simulation is used to compare the performance of a traditional plant with that of a modular plant. Three different factory layouts, namely function-type, flow-line and process-layer, are constructed. The evaluation indexes include production cycle times and the numbers of equipments required. The simulation results reveal the advantages and drawbacks of a modular plant. Thus the feasibility of adopting a modular plant for 300 mm is clarified.

2. A modular IC fabrication facility

Wu and Chiang (1995) proposed a conceptual modular IC fabrication plant. Wu *et al.* (1998) sketched the structure of the proposed plant in Fig. 1. Their modular plant consists of production modules, an AMHS, utility/exhaust/air condition piping systems, and a building for inserting production modules.

Figure 2 shows the production module. The module can be divided into three parts. The top is a fixed clean air supply system. The middle section is the replaceable part. Basically, a modular clean room containing one to three sets of IC machines. The bottom section is fixed like the top section and contains connectors/outlets linking the pipes of the modular clean room to utility/exhaust/air conditioning piping systems. A

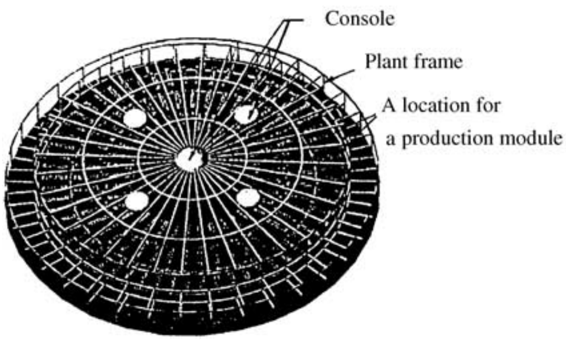

Fig. 1. The structure of a modular plant.

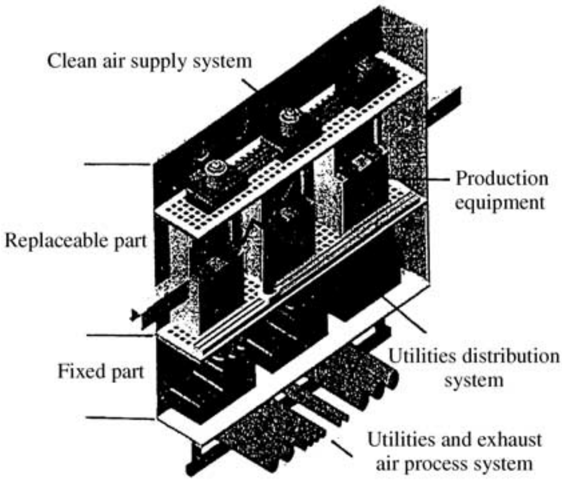

Fig. 2. A production module.

modular clean room resembles a ship container. Heat-resistant walls and air filters and air-conditioners are installed in the clean room. Pipes for chemical materials, exhaust gases, water, air conditioning, etc. can be easily connected or disconnected through the bottom part via stem pipes. When a machine fails, a crane located in the center of the plant can remove the module and replace it with a new one. Moreover, the installation of equipment and facilities can progress simultaneously at different places during the plant's construction. Figure 3 shows the alignment of production modules in a modular plant.

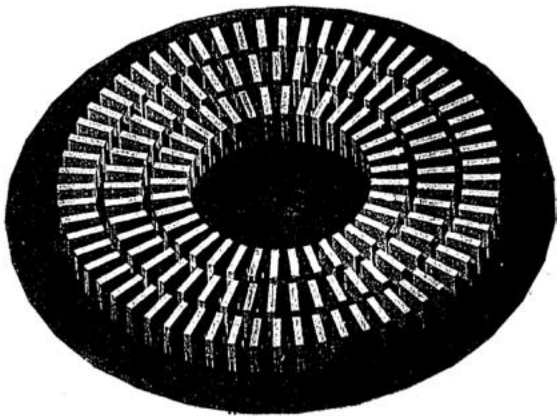

Fig. 3. The alignment of production modules in a modular plant.

3. Modular plant feasibility study

This section examines whether or not a modular plant is feasible for 300 mm wafer fabrications. The following issues are investigated: (1) Can a modular plant maintain reasonable productivity with high equipment failure rate and long repair time? (2) Does a modular plant require more equipment than a traditional one? (3) How should a modular plant be laid out? AutoMod simulation package developed by AutoSimulations, Inc. (1999) is used in this study to build simulation models. Both a traditional and a function-type modular plant models are constructed and compared each other. Three different modular plant models with function-type, flow-line and process-layer layouts are constructed and compared too. The evaluation indexes include production cycle times and the numbers of equipments required. The simulation results reveal the advantages and drawbacks of a modular plant. Thus the feasibility of adopting a modular plant for 300 mm is clarified.

3.1. *Construction of the simulation model*

This study adopts the aggregated model of the full-scale production line in Lu *et al.* (1994). The model consists of 12 stations having one or more identical machines. The entire process requires 60 operations. The processing times at each service station, the time between machine failures, the repair times and the time to replace a production module are all assumed to be exponentially distributed. Figure 4 described the process flow, and Table 1 specifies the plant parameters. This study adopts the first in first out dispatching rule (FIFO). The material release time is a Poisson distribution with a mean of $\lambda = 21$ wafers/h. Since a traditional plant usually adopts a function-type layout, a function-type layout modular plant model with the same plant parameters is constructed to compare with the traditional one. The numbers of each type of machines required are estimated at a monthly production rate 15,000 wafers.

3.1.1. *Traditional plant model*

A spine layout is used and shown in Fig. 5. From simulations, the numbers of machines needed for each station to maintain a monthly production rate 15,000 wafers were estimated and are tabulated in Table 2. The heavy solid line in the middle of the layout is a single-vehicle two-way inter-bay transportation route.

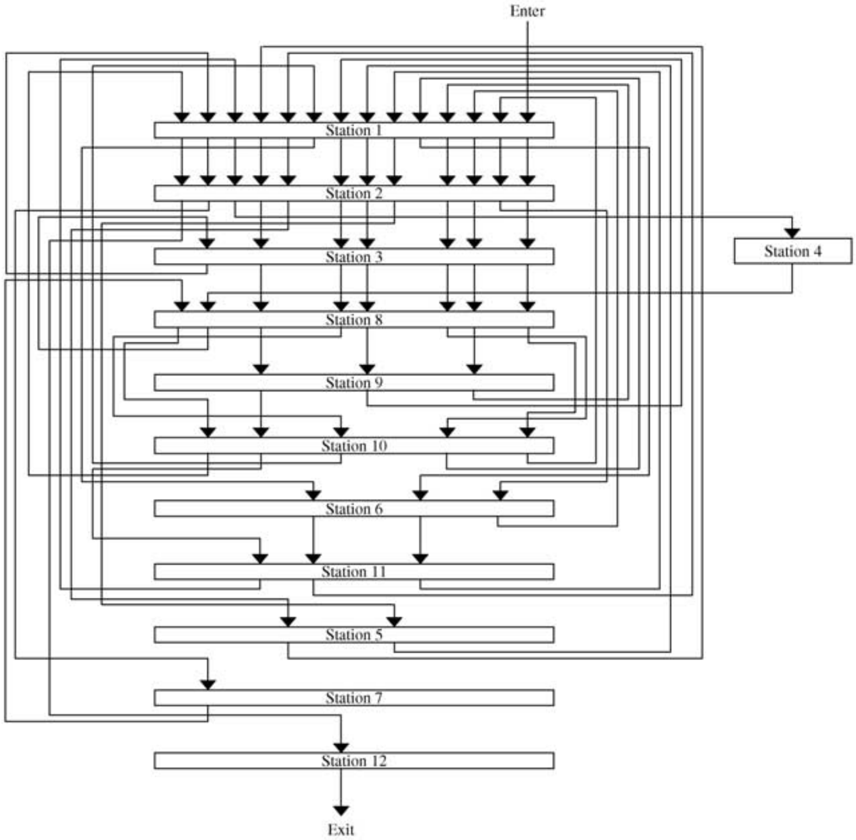

Fig. 4. The process flow of the simulation model (Lu *et al*., 1994).

Table 1. Plant data of the simulation model

Station	*No. of visits*	*MPT*	*MTBF*	*MTTR*	*MTTRPM*
1	14	0.5	150	5	0.5
2	12	0.375	200	9	0.5
3	7	2.5	200	5	0.5
4	1	1.8	200	1	0.5
5	2	0.9	200	1	0.5
6	3	1.2	200	1	0.5
7	1	1.8	200	1	0.5
8	8	0.8	150	5	0.5
9	3	0.6	200	5	0.5
10	5	3.0	130	5	0.5
11	3	1.2	200	5	0.5
12	1	2.5	200	5	0.5

MPT, mean processing time; MTBF, mean time between failures; MTTR, mean time to repair; MTTRPM, mean time to replace a production module.

The dash line in each station is a single-vehicle two-way intra-bay route. The traveling speed is $15\,\mathrm{m\,min}^{-1}$ for both inter or intra-bay vehicles. The width and the length of each station are 5 m and 60 m, respectively. The distance between two conjoint machines is 2 m. An automated stocker is located in every station and its capacity is sufficient for incoming wafers.

3.1.2. *Modular plant model*

The layout of the modular plant is also a function-type. Every production module may contain one to three machines. If a station has five identical machines, it requires two production modules (one containing three machines and the other containing two machines). Figure 6 shows the modular plant layout. The production modules are arranged in circles. These circles are two-way bus routes. The distance between the first circle and the center and

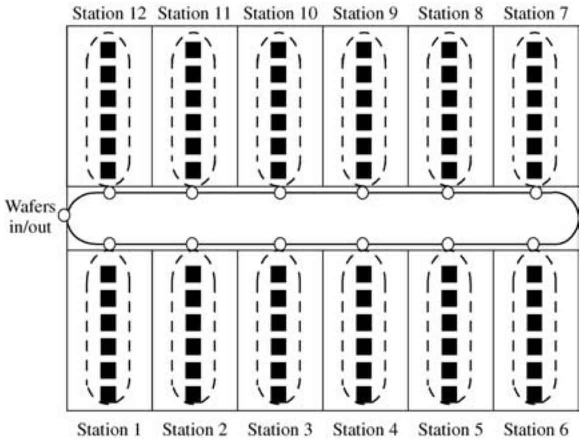

Fig. 5. A spine layout for a traditional plant model.

between each consecutive circle is 15 m, respectively. Since a production module has a limited space, this study assumes that the storage queue length for each production module is 10. To keep a 1500 wafers/month production rate for this modular plant, the number of on-line machine needed for each station and the number of vehicles needed for the whole system were estimated by simulations. Table 2 tabulates the machine numbers. Seven vehicles are required for the whole system. It shows that both traditional and modular systems have the same number of machine needed for a 15,000-wafer-month-production-rate. These on-line machines are arranged as the layout in Fig. 6. A symbol on a production module represents the station number and the number of machines in the station. For example, the symbol, $\substack{8 \\ (3)}$, represents the production module which contains three station-8 machines. These production modules without any symbols are unavailable. The number of off-line (spared) machines required is dependent on the associated mean time to repair (MTTR), and is a good performance index for the evaluation of the feasibility of modular plants.

Table 2. Numbers of machines needed for both traditional and modular plant models

Station	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*Total*
Traditional	13	8	30	4	4	7	4	12	4	27	7	5	125
Modular	13	8	30	4	4	7	4	12	4	27	7	5	125

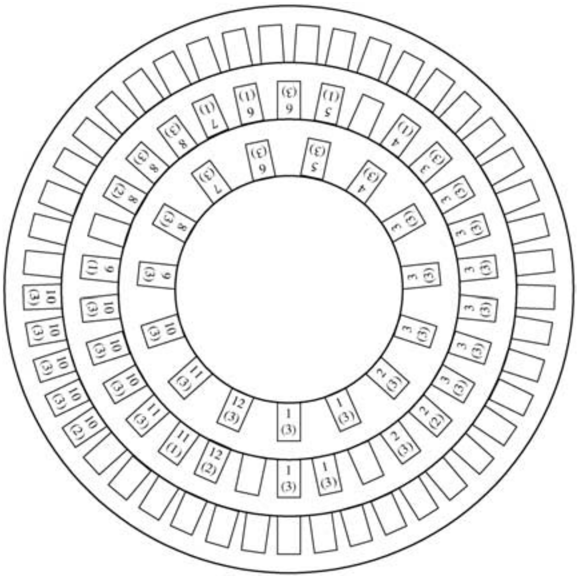

Fig. 6. The modular plant layout obtained from simulations.

3.2. *AutoMod simulations*

In order to investigate the feasibility of a modular plant, the number of total (on-line + off-line) machines required and production cycle times for different mean times between failure (MTBF), MTTRs, and mean times to replace a production module MTTRPM were estimated. Simulations were performed and compared with 1 time, 4/5 times and 2/3 times of the original MTBF, 1 time, 1.5 times, 2 times, 2.5 times and 3 times of the original MTTR, and 1 time, 2 times, 3 times and 4 times of the original MTTRPM (shown in Table 1). Table 3 assigns numbers to each of MTBF and MTTR used in this study. For each set of data, 10 times of simulations with different random seeds are performed. The simulation time is 36 months and the warm up period is 3 months.

3.2.1. *Comparison of cycle times*

This study gradually reduces MTBF and increases MTTR of the traditional plant to examine how MTBF and MTTR affect cycle times. Similarly, in the modular plant study, we also reduce MTBF and increase MTTRPM to examine how MTBF and MTTRPM affect cycle times. MTTR does not directly affect the performance of a modular plant. However, large MTTR may increase the numbers of off-line machines required. This phenomenon will be discussed next. Figures 7 and 8 compare cycle times.

Table 3. To assign numbers to each MTBF and MTTR, respectively

MTBF numbers			*MTTR numbers*				
No. 1	No. 2	No. 3	No. 1	No. 2	No. 3	No. 4	No. 5
1 time	4/5 times	2/3 times	1 time	1.5 times	2 times	2.5 times	3 times

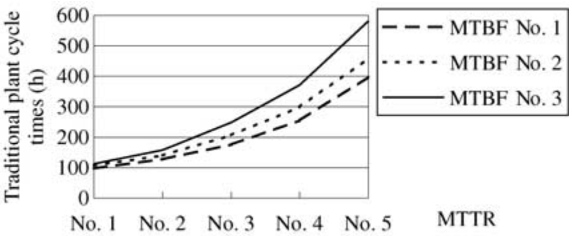

Fig. 7. The traditional plant cycle time changes given various plant data.

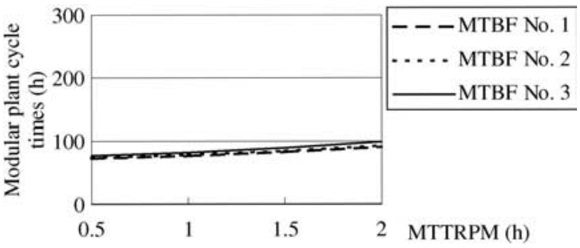

Fig. 8. The modular plant cycle time changes given various plant data.

According to these figures, MTBF and MTTR affect cycle times of the traditional plant more than MTBF and MTTRPM affect those of the modular plant. Since the MTBF in both cases is the same, MTTR influences the traditional plant is much more than MTTRPM does the modular plant. Therefore, plant data influence a modular plant to a lesser extent.

3.2.2. *Comparison of machine numbers*

The next step is to find out whether a modular plant requires more machines than a traditional plant to maintain a productivity level of 15,000 wafers/month. Tables 4, 5 and 6 tabulate the results. Table 4 illustrates the number of machines required and the utilization for each station in the traditional plant at different MTBF and MTTR. According to this table, the total number of machines increases from 125 to 900 to maintain 15,000-wafer/month productivity when MTBF falls by two thirds and MTTR increases by three times. Simultaneously, the average station utilization drops from 78.37% to 9.58%. Since the on-line number of machines required for each station to

Table 4. The number of machines required and the average utilization for each station in the traditional plant

Station	*MTBF No. 1 and MTTR No. 1*		*MTBF No. 1 and MTTR No. 5*		*MTBF No. 2 and MTTR No. 5*		*MTBF No. 3 and MTTR No. 5*	
	No. of machines	*Utilization*	*No. of machines*	*Utilization*	*No. of machines*	*Utilization*	*No. of machines*	*Utilization*
1	13	78.76	50	20.03	100	9.31	130	7.19
2	8	80.32	45	11.64	80	6.34	120	4.27
3	30	85.12	75	34.45	180	13.48	230	9.23
4	4	65.75	5	53.34	7	36.24	10	25.25
5	4	64.37	5	52.12	7	36.17	10	25.74
6	7	73.45	10	53.30	15	35.65	20	25.46
7	4	64.77	5	53.80	7	36.40	10	25.12
8	12	80.16	50	17.16	80	11.17	130	6.11
9	4	63.67	5	54.24	7	35.24	10	25.21
10	27	80.18	70	30.38	160	12.12	200	9.37
11	7	77.21	10	52.95	15	33.64	20	25.21
12	5	72.20	7	50.11	8	43.98	10	35.74
Total	125	78.37	337	28.41	666	13.66	900	9.58

Table 5. The number of off-line production modules required for each station in the modular plant

Station	*MTTR No. 1*	*MTTR No. 2*	*MTTR No. 3*	*MTTR No. 4*	*MTTR No. 5*
1	5(3)	6(3)	7(3)	8(3)	8(3)
2	4(3),1(2)	4(3),2(2)	5(3),2(2)	5(3),2(2)	5(3),2(2)
3	7(3)	8(3)	9(3)	10(3)	10(3)
4	2(3),1(1)	2(3),1(1)	2(3),1(1)	2(3),1(1)	2(3),1(1)
5	1(3),1(1)	1(3),1(1)	2(3),1(1)	2(3),1(1)	2(3),1(1)
6	2(3),1(1)	2(3),1(1)	2(3),1(1)	2(3),1(1)	2(3),1(1)
7	2(3),1(1)	2(3),1(1)	2(3),1(1)	2(3),1(1)	2(3),1(1)
8	4(3),1(2)	4(3),2(2)	5(3),2(2)	5(3),2(2)	5(3),2(2)
9	2(3),1(1)	2(3),1(1)	3(3),1(1)	3(3),1(1)	3(3),1(1)
10	6(3),2(2)	7(3),2(2)	7(3),3(2)	9(3),3(2)	10(3),3(2)
11	3(3),1(1)	3(3),1(1)	4(3),1(1)	4(3),1(1)	4(3),1(1)
12	3(3),1(2)	3(3),1(2)	3(3),1(2)	3(3),1(2)	3(3),1(2)
Total	139	152	175	187	190

maintain the 15,000 wafer/month modular plant is the same as that of the traditional plant, Tables 5 and 6 only tabulate the off-line and the total (on-line + off-line) number of machines required for each station. Table 6 also shows the station utilization of the modular plant. In both Tables 5 and 6, only MTTR plant data was used to distinguish each simulation. This is because that simulation result shows MTBF or MTTRPM does not significantly influence the number of machines required. Table 6 indicates that the total number of machines increases from 264 to 315 to maintain 15,000-wafer/month productivity when MTTR increases by three times. The total number of machines required for the traditional plant initial model (125) is less than that required for the modular plant initial model (264). However, when MTTR is increased by three times, the total number of machines required for the traditional plant (900) is much more than that required for the modular plant (315). From the perspective of station utilization, the modular plant is more stable (between 36.01% and 30.49%) than the traditional plan (between 78.37% and

Table 6. The number of total machines required (off-line + on-line)and the average utilization for each station in the modular plant

Station	*MTTR No. 1*		*MTTR No. 2*		*MTTR No. 3*		*MTTR No. 4*		*MTTR No. 5*	
	Total machine number	*Machine utilization*	*Total machine number*	*Machine utilization*	*Total machine number*	*Machine utilization*	*Total machine number*	*Machine utilization*	*Total machine number*	*Machine utilization*
1	28	35.23	31	31.82	34	29.01	37	26.66	37	26.66
2	22	27.34	24	25.06	27	22.27	27	22.27	27	22.27
3	51	49.39	54	46.64	57	44.19	60	41.98	60	41.98
4	11	23.58	11	23.58	11	23.58	11	23.58	11	23.58
5	8	32.31	8	32.31	11	32.31	11	32.31	11	32.31
6	14	35.56	14	35.56	14	35.56	14	35.56	14	35.56
7	11	21.76	11	21.76	11	21.76	11	21.76	11	21.76
8	26	35.46	28	32.92	31	29.74	31	29.74	31	29.74
9	11	21.96	11	21.96	14	17.25	14	17.25	14	17.25
10	49	43.55	52	41.03	54	39.51	60	35.58	63	33.87
11	17	29.63	17	29.63	20	25.18	20	25.18	20	25.18
12	16	21.52	16	21.52	16	21.52	16	21.52	16	21.52
Total	264	36.01	277	32.22	300	32.01	312	30.78	315	30.49

Table 7. The classification of the 60 operations into 14 process layers

Process layer	*Operations in the process layer*	*Layer process time*
Layer 1	Enter→1→2→3→8→10	7.175
Layer 2	→1→2→6	2.075
Layer 3	→1→2→3→8→9	4.775
Layer 4	→1→2→3→8→10	7.175
Layer 5	→1→6→11	2.9
Layer 6	→1→2→5	1.775
Layer 7	→1→2→3→8→9	4.775
Layer 8	→1→2→3→8→10	7.175
Layer 9	→1→6→11	2.9
Layer 10	→1→2→5	1.775
Layer 11	→1→2→3→8→9→10→11	8.975
Layer 12	→1→2→4→8→3	5.975
Layer 13	→1→2→7→8→10	6.475
Layer 14	→1→2→12→Exit	3.375
Total process time		67.3

9.58%). According to the model process operation flow, stations 1, 2, 3, 8, and 10 are the stations that have a larger workload than the others have. The numbers of the bottleneck machines required in the modular plant are much smaller than that required in the traditional plant. This indicates the modular plant does reduce the influences of MTBF and MTTR. The numbers of the non-bottleneck machines in the modular plant are larger than that in the traditional plant. This is because of off-line module required in a modular plant. To reduce influence on bottleneck stations results the smaller number of machines required and streamlines the IC production process. Thus, a modular plant performs better than a traditional one when machine repair time is long.

3.3. *Summary*

Simulation results show that: (1) The on-line machine required for both a traditional plant and a function-type modular plant are the same. (2) The average of production cycle times of a modular plant is always better than that of a traditional plant under any MTBF and MTTR; in fact, MTTR does not affect the cycle time of a modular plant at all. (3) The total machines required of a traditional plant are much less than that of a modular plant to maintain a stable production rate when machine maintenance is in good condition; however, if the probability of machine-breakdown or repairing-time increase, a modular plant can maintain the production rate with much less machines than a traditional plant required. Conclusively, a modular plant could be a good choice when machines break down frequently or machine maintenance is not convenient.

4. Modular plant layout study

A modular plant is feasible when machines break down frequently or machines' repair-times are long. The modular plant layout used in the above study is a function-type. It is known that a layout greatly affects

Table 8. A reasonable way to group 14 process layers in to N areas

Process layer	*Number of areas*													
Area 1	$N=1$	$N=2$	$N=3$	$N=4$	$N=5$	$N=6$	$N=7$	$N=8$	$N=9$	$N=10$	$N=11$	$N=12$	$N=13$	$N=14$
Layer 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1
Layer 2	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 1	Area 2	Area 2	Area 2	Area 2	Area 2	Area 2
Layer 3	Area 1	Area 1	Area 1	Area 1	Area 1	Area 2	Area 2	Area 2	Area 2	Area 2	Area 2	Area 3	Area 3	Area 3
Layer 4	Area 1	Area 1	Area 1	Area 2	Area 2	Area 2	Area 2	Area 2	Area 3	Area 3	Area 3	Area 4	Area 4	Area 4
Layer 5	Area 1	Area 1	Area 2	Area 2	Area 2	Area 3	Area 3	Area 3	Area 4	Area 4	Area 4	Area 5	Area 5	Area 5
Layer 6	Area 1	Area 1	Area 2	Area 2	Area 2	Area 3	Area 3	Area 3	Area 4	Area 4	Area 4	Area 5	Area 5	Area 6
Layer 7	Area 1	Area 1	Area 2	Area 2	Area 3	Area 3	Area 3	Area 3	Area 4	Area 5	Area 5	Area 6	Area 6	Area 7
Layer 8	Area 1	Area 2	Area 2	Area 3	Area 3	Area 4	Area 4	Area 4	Area 5	Area 6	Area 6	Area 7	Area 7	Area 8
Layer 9	Area 1	Area 2	Area 2	Area 3	Area 3	Area 4	Area 4	Area 5	Area 6	Area 7	Area 7	Area 8	Area 8	Area 9
Layer 10	Area 1	Area 2	Area 2	Area 3	Area 4	Area 4	Area 5	Area 5	Area 6	Area 7	Area 7	Area 8	Area 9	Area 10
Layer 11	Area 1	Area 2	Area 3	Area 3	Area 4	Area 5	Area 5	Area 6	Area 7	Area 8	Area 8	Area 9	Area 10	Area 11
Layer 12	Area 1	Area 2	Area 3	Area 4	Area 5	Area 5	Area 6	Area 7	Area 8	Area 9	Area 9	Area 10	Area 11	Area 12
Layer 13	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9	Area 10	Area 10	Area 11	Area 12	Area 13
Layer 14	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9	Area 10	Area 11	Area 12	Area 13	Area 14

Table 9. The number of on-line machine needed for each case ($N = 1–14$)

Number of areas	$N=1$	$N=2$	$N=3$	$N=4$	$N=5$	$N=6$	$N=7$	$N=8$	$N=9$	$N=10$	$N=11$	$N=12$	$N=13$	$N=14$
Station 1	13	14	15	14	14	14	14	14	14	14	14	14	14	14
Station 2	8	9	9	8	10	10	12	12	12	12	12	12	12	12
Station 3	30	31	31	32	33	33	34	34	35	35	35	35	35	35
Station 4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Station 5	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Station 6	7	8	6	9	9	9	9	9	9	9	9	9	9	9
Station 7	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Station 8	12	12	13	12	13	13	15	15	16	16	16	16	16	16
Station 9	4	5	6	6	6	6	6	6	6	6	6	6	6	6
Station 10	27	27	28	29	30	30	30	30	30	30	30	30	30	30
Station 11	7	8	8	8	9	9	9	9	9	9	9	9	9	9
Station 12	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Total	125	131	133	135	141	141	146	146	148	148	148	148	148	148

performance. Thus, in this section, we compares three layouts, namely function-type, flow-line and process-layer (Chang and Chang, 1998). Transportation problems exist and are considered in this section. A simple design of AMHS which including two individual systems for inter- and intra-bays, respectively, is adopted. The efficiency of AMHS will not be discussed in this paper. The production process and the manufacturing conditions used in the above study are also applied here.

4.1. *Model construction and simulations*

The main purpose of a process-layer layout is to reduce the possibility of the long traveling time of a function–type layout and the low machine utilization of a flow-line layout. The plant is divided into N areas. Each area includes equipment that can process one or more process layers. A process layer generally includes at least six operations: thinfilm, photo, etching, ion implant, diffusion and test, and can be distinguished from another process layer by photo operations. Thus, a complete set of operations that, from a given photo operation to the next photo operation, is called a process layer. When $N = 1$, it is a function-type layout, and when $N = 14$ in this case, it is a flow-line layout. Since previous investigations have not specified which operations in Lu's processing operations are photo operations, this study defines a process layer to be a set of successive operations in which no two operations are the same. According to this definition, the 60 operations are classified into 14 process layers and tabulated in Table 7. Clearly, every process layer starts from station 1 implying that operations at station 1 are photo operations. Next, these 14 process layers must be grouped into N areas. To ensure balance along the line, the total processing time in each area should be very close. After performing simulations and processing time analyses, a reasonable grouping way and the numbers of on-line machine and vehicles needed for each case are obtained and tabulated in Tables 8, 9 and 10, respectively. Simulation models for the 14 cases, including 1 function-type when $N = 1$, 1 flow-line when $N = 14$ and 12 process-layer layouts, are constructed and will be analyzed in the next section.

4.2. *Performance analysis*

Nearly 14 modular plant layouts models are constructed. Simulations are performed and compared. The performance indexes are cycle times and total machine numbers required. After 10 times of simulations for each case, the average cycle time and the average number of off-line machine needed for each case are obtained.

Figure 9 illustrates the changes of cycle times for these 14 plant layouts. One can see that a trend exists. That indicates that the cycle time has a relationship with the number of areas. Although the 10-area process-layer plant layout reaches the minimum value of the cycle times, the cycle times of these 9–14-area layouts are very close to that of 10-area layout. From a

Table 10. The number of vehicles needed for each case ($N = 1$–14)

Number of areas	$N=1$	$N=2$	$N=3$	$N=4$	$N=5$	$N=6$	$N=7$	$N=8$	$N=9$	$N=10$	$N=11$	$N=12$	$N=13$	$N=14$
Inter-bay vehicles	0	1	1	1	1	1	1	1	1	1	1	1	1	1
Intra-bay vehicles														
Area 1	7	3	2	1	1	1	1	1	1	1	1	1	1	1
Area 2	—	4	2	2	1	1	1	1	1	1	1	1	1	1
Area 3	—	—	2	2	1	1	1	1	1	1	1	1	1	1
Area 4	—	—	—	1	1	1	1	1	1	1	1	1	1	1
Area 5	—	—	—	—	1	1	1	1	1	1	1	1	1	1
Area 6	—	—	—	—	—	1	1	1	1	1	1	1	1	1
Area 7	—	—	—	—	—	—	1	1	1	1	1	1	1	1
Area 8	—	—	—	—	—	—	—	1	1	1	1	1	1	1
Area 9	—	—	—	—	—	—	—	—	1	1	1	1	1	1
Area 10	—	—	—	—	—	—	—	—	—	1	1	1	1	1
Area 11	—	—	—	—	—	—	—	—	—	—	1	1	1	1
Area 12	—	—	—	—	—	—	—	—	—	—	—	1	1	1
Area 13	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Area 14	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Intra-bay total	7	6	6	6	5	6	7	8	9	10	11	12	13	14

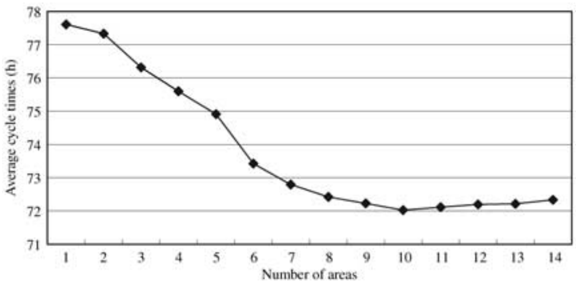

Fig. 9. The changes of cycle times for different plant layouts.

statistics point of view, 9–14-area plant layouts are as good as 10-area layout.

Tables 9 and 11 summarize the number of on-line and off-line machines required for each station. One can see that the number of on-line machine needed is gradually increased by the number of areas. A function-type layout needs the minimum on-line machines. This is because a high integration system can share resources, have high resource utilization, and thus reduce total number of resources required. A layout with fewer areas has higher integration. As for the numbers of off-line machine required in Table 11, they are somewhat random. Therefore, the total number of machines required (Fig. 10) could hardly see any relationship with the number of areas of a layout. Though, in this case, the flow-line layout has the minimum total machines required, the difference between one another is not significant enough. We conclude that the total number of machine required is independent on the number of areas.

Table 10 summarizes the number of vehicles needed for each layout. It shows a layout with more areas needs more vehicles. AMHS is a very complicated problem in IC fabrications. A good design of AMHS may result different number of vehicles needed. Hence, the number of vehicles required is not used as a performance index here.

4.3. *Summary*

Simulation results clearly indicate that: 1. The process-layer layouts with a moderate number of areas can provide good production cycle times. 2. Though function-type layout requires the minimum on-line machines, the total number of machines required of a layout is independent on the number of areas of a layout, i.e., a process-layer layout may require fewer machines than a function-type layout does. Based on the two findings, we conclude that a process layer layout is a reasonable approach for a modular plant.

Table 11. The number of off-line machine required for each case $(N = 1\text{–}14)$

Number of areas	$N=1$	$N=2$	$N=3$	$N=4$	$N=5$	$N=6$	$N=7$	$N=8$	$N=9$	$N=10$	$N=11$	$N=12$	$N=13$	$N=14$
Station 1	18	19	19	22	24	25	24	25	25	18	18	16	14	10
Station 2	18	21	18	10	12	14	20	16	16	17	15	10	9	9
Station 3	21	24	24	24	31	31	30	30	30	27	30	33	29	27
Station 4	8	8	8	8	8	8	8	8	11	8	8	11	8	8
Station 5	8	6	8	6	6	6	6	4	4	6	6	6	6	6
Station 6	11	13	8	9	9	9	9	9	9	9	9	9	9	9
Station 7	8	8	8	8	8	11	8	8	8	8	11	8	8	9
Station 8	20	15	23	15	23	19	21	23	14	12	12	14	16	14
Station 9	12	15	29	10	8	8	12	8	10	8	10	8	8	8
Station 10	27	30	29	30	24	24	24	24	24	24	27	24	30	24
Station 11	21	18	18	18	15	15	15	12	12	12	15	12	12	12
Station 12	15	15	18	13	15	15	15	15	12	15	15	15	15	13
Total	187	192	210	173	183	185	192	182	175	164	176	166	164	149

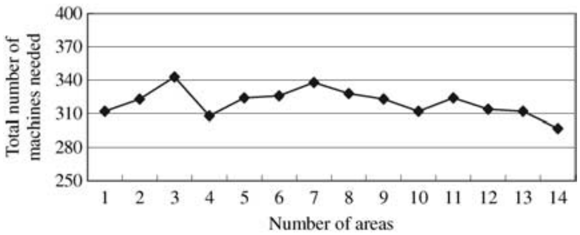

Fig. 10. The total number of machine needed for different plant layout.

5. Conclusions

A feasibility study of a modular plant has been carried out. Simulation results indicate that: (1) A modular plant can maintain a reasonable productivity with high equipment failure rate and long repair time. (2) A modular plant requires less equipment than a traditional one does when machines break down frequently or machine maintenance is very time-consuming. (3) A process-layer layout with a moderate number of areas is a good approach.

Simulations performed in this paper are concerned with a 60-step-single-product case, which is relatively simple. More simulation analyses on cases concerned with a product with more than 500 steps or multi-products are our future work. A design of an AMHS can affect the efficiency of a plant much. Hence, an AMHS design study for a process-layer modular plant is also a major task of our future work.

Acknowledgment

The authors would like to thank the National Science Council of the Republic of China for financially supporting this research under Contract No. NSC-89-2212-E-002-064.

References

AutoMod User's Manual, AutomSimulations, Inc., Utah, USA, June 1999.

Chang, C. F. and Chang, S. K. (1998) A layer-based layout approach for semiconductor fabrication facilities. *IEEE Symposium on Advanced Semiconductor Manufacturing Conference and Workshop*, 23–25 September, pp. 385–390.

Christopher, D., Rieko, H., Christos, G. T. and Uzsoy, R. (1997) Alternative facility layouts for semiconductor wafer fabrication facilities. *IEEE Transactions on Components, Packaging, and Manufacturing Technology—Part C*, Vol. 20, No. 2, April, pp. 152–163.

Jefferson, T. and Willbrandt, J. (1999) Reducing labor requirements for 300 mm factories with intrabay automation. *IEEE International Symposium on Semiconductor Manufacturing Conference Proceedings*, 11–13 October, pp. 77–80.

Kurosaki, R., Nagao, N., Komada, H., Watanabe, Y. and Yano, H. (1997) AMHS for 300 mm wafer. *IEEE International Symposium on Semiconductor Manufacturing Conference Proceedings*, 6–8 October, pp. D13–D16.

Lu, C. H. S., Ramaswamy, D. and Kumar, P. R. (1994) Efficient scheduling policies to reduce mean and variance of cycle-time in semiconductor manufacturing plants. *IEEE Transactions on Semiconductor Manufacturing*, **7**(3), 374–388.

Peters, B. A. and Yang, T. (1997) Integrated facility layout and material handling system design in semiconductor fabrication facilities. *IEEE Transactions on Semiconductor Manufacturing*, **10**(3), 360–369.

Pierce, N. G. and Stafford, R. (1994) Modeling and simulation of material handling for semiconductor wafer fabrication. *Proceedings of the 1994 Winter Simulation Conference*, pp. 900–906.

Pillai, D., Quinn, T., Kryder, K. and Charlson, D. (1999) Integration of 300 mm fab layouts and material handling automation. *IEEE International Symposium on Semiconductor Manufacturing Conference Proceedings*, 11–13 October, pp. 23–26.

Plata, J. J. (1997) 300 mm fab design—a total factory perspective. *IEEE International Symposium on Semiconductor Manufacturing Conference Proceedings*, 6–8 October, pp. A5–A8.

Schroeder, J. P. (1997) Automation-centric processing bay layout. *Semiconductor International*, **20**(6), 209–214.

Weiss, M. (1996) Semiconductor factory automation. *Solid State Technology*, **39**(5), 89–96.

Weiss, M. (1997) 300 mm fab automation technology options and selection criteria. *IEEE Symposium on Advanced Semiconductor Manufacturing Conference and Workshop*, 10–12 September, pp. 373–379.

Wu, B. P. and Chiang, S. C. (1995) A proposed architecture for economical flexible automated semiconductor manufacturing. *Taiwan Packaging Seminar*, SEMI, Hsinchu, Taiwan.

Wu, B. P., Lee, H. C., Hsu, C. Y. and Chang, C. F. (1998) A modular-based clean room. in *Chinese, Lecture Notes*, November 26, 1998, Energy and Resources Laboratories, pp. 1–20.