A Genetic Algorithm for Optimizing Facility Layout in a Wafer Fab

Michael H. Hu, Meei-Yuh Ku[*], Chao-Chi Chen

Abstract—**In this research, the Genetic Algorithm (GA) and Space-Filling Curve (SFC) are combined along with the use of Taguchi method for finding the optimal combination of parameters. The new algorithm has been tested on 12 cases of spine-type facility layout for four different material handling directions, e.g. clockwise one-way, two-way, clockwise one way with a shortcut and two-way with a shortcut to compare their cost differences. Results obtained in this research are analyzed and compared with those acquired using other algorithms. The efficiency of problem solving using this algorithm exceeds 96% and the optimal solution for a test case consisting of 20 bays is much superior to all other known optimal solutions.**

Keywords: **Genetic Algorithm, Spine Layout, Space-Filling Curve**

I. INTRODUCTION

The wafer fab. processing is highly reentrant with super frequent material handling and moving. If the material transportation were handled with traditional human labor, the efficiency would be extremely low and the damage rate would be exceptionally high due to vibration. Additionally, the capital investment for building a wafer fab. is huge; a 12-inch wafer plant costs at least $2.5 billions in addition to costly wafer manufacturing machinery. Thus, improving the efficiency of the production facilities is of great importance that is closely related to the layout and automation of material handling system.

Langevin *et al.* (1994) first proposed the spine arrangement to be implemented in two phases for minimizing the material transporting and investment costs[1]. Yang & Peters (1997) recommended the combination of the spine and shortcut arrangements utilizing the quadratic set covering problem (QSCP) method to construct a mathematical algorithm for planning the material handling system and its layout in the semi-conductor factory[2]. They applied the space-filling curve concept and network flow method on the laying out spine and perimeter arrangements with the objective of minimizing the wafer transportation distance[3]. Ting & Tanchoco (2001) targeted the design of rail for material handling in a wafer fab. by proposing two straight-line arrangements and mathematical modes in order to search for the minimum path for transporting materials[4].

Griger *et al.* (1997) targeted the influence of various foundry layouts on the production cycle time[5]. Kurosaki *et al.* (1997) compared two different automatic material handling system and the associated foundry layout problems[6]. Plata (1997) studied the layout and design of 300-mm wafer foundry[7]. Cambell & Laitinen (1997) proposed the installation of wafer handling system on the Zero Foot Print Automation (ZFPA) system by combining the Microstock design method[8].

Sikich (1998) emphasized the consideration of safety, price, effectiveness, attached conditions and operational conditions by the system users and how to develop a method for testing the automatic material handling system in order to assure a well-arranged operation of the factory systems[9]. Briam *et al.* (1999) proposed the Continuous Flow Transport (CFT) technology for factory arrangement that is obviously effective in increasing the factory building capacity and reducing the arrival time for moving wafers[10]. Pillai *et al.* (1999) studied the concept of the optimal combination of multi-functional layout, automatic material handling system and facility operation for a 300-mm wafer Fabs[11].

The aforementioned literature review shows that most researchers had studied the facility layout and material handling method in a foundry; few of them utilized an algorithm to investigate the problem of facility layout and material handling. In this research, the genetic algorithm is combined with the Taguchi method to find the optimum combination of parameters; this algorithm is compared with the simulated annealing algorithm and two-phase algorithm

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based on the calculation time and the calculated material handling cost.

The major motive of this research is to implement a facility planning method to improve the facility layout and material handling system for existing foundries such that the material handling in the interbay system of a foundry can be solved through the use of generic algorithm. The objective is to obtain the optimal layout plan under of reasonable problem constraints such as the calculation time and the solution quality for reducing the water moving distance, raising the machine usage and lowering wafer manufacturing cost.

Additionally, this research will target the facility layout for a spine foundry arrangement to develop a heuristic algorithm that can be used to obtain the optimum or approximate optimum answers within a reasonable problem-solving time in addition to utilizing the characteristics of space-filling curve to solve for the optimal or near-optimal layout. The following tasks will also be completed in this research:

1) To collect and compile information and data on facility layout and automatic material handling system implemented in current wafer foundries.
2) To design and develop the generic algorithm based software applicable to the spine configuration system to be used for future teaching and research.
3) To further investigate the generic algorithm developed in this research by analyzing the results obtained with this algorithm and comparing the results with those obtained using other available algorithms that has been published in literature.

II. MODEL DEVELOPMENT

This research targets the layout of foundry spine configuration system and the input is limited to quantitative material flow data without using qualitative information. The QSCP model expressed in the following form is used:

$$\text{Minimize} \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=1}^{I(i)} \sum_{l=1}^{I(j)} \varepsilon_{ij} u_{ij} \delta_{ikjl} \xi_{ik} \xi_{jl} \qquad (1)$$

Subject to：

$$\sum_{k=1}^{I(i)} \xi_{ik} = 1 \qquad \forall i \qquad (2)$$

$$\sum_{i=1}^{N} \sum_{k=1}^{I(i)} \alpha_{ikt} \xi_{ik} \leqq 1 \qquad \forall t \qquad (3)$$

$$\xi_{ik} \in \{0,1\} \text{ for } i = 1,\dots,N \text{ and } \forall k \in I(i) \qquad (4)$$

Where

N : the number of bays in facility layout;
i , j : bay's numbering, from i to N;
t : index for the unit rectangular block in the floor space;
ε_{ij} : unit handling chrge from the ith bay to the jth bay;
u_{ij} : the directed flow density from ith bay to the jth bay;
δ_{ikjl} : the flow distance from the kth replacement of the ith bay to the lth replacement of the jth bay;
ξ_{ik} = 1 if bay i is assigned to its kth candidate location; otherwise it is equal to 0
ξ_{jl} = 1 if bay j is assigned to its lth candidate location; otherwise it is equal to 0
$I(i)$: the set of candidate locations of bay i;
k : index for candidate locations; $k = 1,\dots |I(i)|$
α_{ikt} = 1 if $t \in J_i(k)$; otherwise it is equal to 0 ;
$J_i(k)$: the set of blacks occupied by bay i if it is assigned to its kth lcation ;

Equation (1) is the objective function for the design of spine configuration facility layout; constraint (2) implies that each bay can only be placed at one position; constraint (3) indicates that one position can only be occupied by one bay and constraint (4) specifies the range of variable values.With various bays have different area, Eq (5) represents the objective function; the constraints are replaced using the spacing-fill curve method.

$$\text{Minimize} \quad Z = \sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij}\, d_{ij} \qquad (5)$$

Where:

Z : the total expectation cost
n : the number of work bays at the sides of the AMHS
i : 1,2,….n
j : 1,2,….n
f_{ij} : the flow quantity between bay i to bay j, $f_{ij} = f_{ij} = 0.$
d_{ij} : the flow distance between bay i to j, $d_{ij} = d_{ij} = 0.$

The semi-conductor factory adopts the AMHS equipment in which various materials have different moving directions thus the formula for calculating the material moving distance between two bays may be distinct. In this research, four different material moving directions, i.e. clockwise one-way, two-way, two-way plus one shortcut and clockwise on-way plus one shortcut, were investigated and experimented in order to obtain reasonable solutions.

A. Research hypothesis

Together with the features of wafer fabs' facility layout and improvement of spine facility layout, the research hypothesis is established as close to the current layout of wafer fabs as possible. The conditions of the research hypothesis are set out below:

- Single floor.
- Considerations accorded only to material flow conditions between work bays.
- The material handling system is the suspended central overhead traveling crane system, which has an infinite number of handling vehicles and does not have lock,

collision or waiting issues.

- There are four considerations for material moving directions: single direction (clockwise), double directions, double directions plus one shortcut and single direction clockwise plus one shortcut.
- The central overhead traveling crane provides the dividing line of the spine layout. One is the northern area (represented in N) while the other is the southern area (represented in S). These two areas have the same width and length.
- The area of each work bay is rectangular.
- Work bays are indivisible and their floor areas cannot be adjusted.
- One side of each work bay in these two areas must be adjacent to the central overhead traveling crane
- The temporary stock area is located in the central point of the work bays' exits adjacent to the central overhead traveling crane.

The distance between two departments refers to the distance between the center of each department. In this research, the calculation of the center of a department is categorized into two methods so the distance between two departments is oaccording to two calculation methods: the distance between the centers of gravity of two departments and the distance between temporary stock areas.

B. Distance between the Unit Centers

In order to compare with the results obtained by other researchers, two unit center methods will be used:

Method 1: Gravitation Center Method

The four corners of a rectangle are assumed to have coordinates (X_i, Y_i); the center of the i^th^ unit is thus (C_{ix}, C_{iy}) and can be calculated as:

$$C_{ix} = \frac{\sum_{i=1}^{4} x_i}{4} \qquad C_{iy} = \frac{\sum_{i=1}^{4} y_i}{4} \qquad (6)$$

Method 2: Temporary Storage Area Method

This method is more suitable for the actual material movement in current wafer foundry. The temporary storage area in each unit is taken to be the center for calculating distance. Coordinates of the two outside corners of unit i that are adjacent to the central ceiling vehicle system are assumed to be (X_{i1}, Y_{i1})、(X_{i2}, Y_{i2}); the coordinate of the temporary storage area is (C_{ix}, C_{iy}). Thus：

$$C_{ix} = \frac{x_{i1} + x_{i2}}{2} \qquad (7)$$

$$C_{iy} = y_{i1} = y_{i2}$$

III. EXPERIMENTAL DESIGN AND RESULT ANALYSES

Values assumed for parameters in the search of the optimal solution using the generic algorithm affect to a great extent the quality of final solutions. Hence, based on review of test example cases published in literature, reasonable values were assumed for relevant parameters, and the Taguchi Method was used in order to find a stable and suitable parameter level combination to be used for obtaining the optimal solution.

The MiniTab statistical package was used to calculate the S/N values of various combinations of L_{16} (4^4) in the orthogonal array and the average S/N values under each factor level**.** Finally, these average S/N values were plotted to form the S/N response graph (Fig. 1) for showing the optimum factor combination.

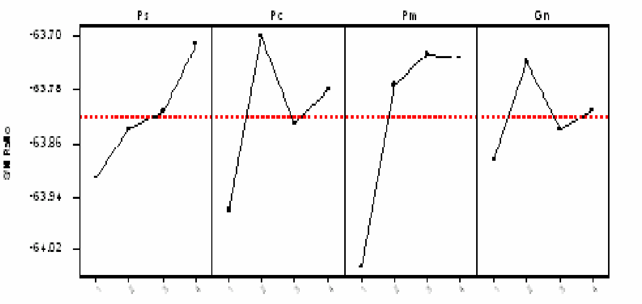

Fig. 1 Main Effects Plot for S / N

A. Comparison of Accomplishments After Improvement

The optimum level combination of factors is used to find the optimum solutions to the 12 example cases using 10 tests per case; the results were compared with known results to complete the analyses.

B. Comparisons and Analyses of the Generic Algorithm, Enumeration Algorithm and Two-Phase Algorithm

As the calculated distance is concerned, Table 1 shows that the optimum solution can be obtained for examples 1 – 7 using the generic algorithm. The time needed for solving examples 11 and 12 using the enumeration algorithm is too long thus only the available data are assumed as the approximate optimum transporting distance and calculation time. Using the generic algorithm on example 12 (20 bays), the calculated optimum distance is 33,462 m, which is better than the 34,121 m so-far known as the optimum solution.

Since the facility layout problem is NP-Complete in nature, the calculation time will increase exponentially with the number of bays involved. When seeking the solution for 14 bays, the calculation times are 504,187 seconds (about 5.8 days) using the enumeration algorithm and only

4,028 seconds (about 1.05 hours) using the two-phase method but only 40 seconds using the generic algorithm for obtaining the optimum solutions. Hence, the generic algorithm is far superior to either the enumeration algorithm or the two-phase method because of the extremely short calculation time (Table 2).

Table 1. Comparisons of distance between the EA,TP and G A

Example	Algorithm		
	Enumeration	Two Phase	Generic
Ex.1：8 Bays	2,667	2,667	2,666.8
Ex.2：9 Bays	5,380	5,380	5,379.5
Ex.3：10 Bays	6,613	6,613	6,612.7
Ex.4：11 Bays	7,695	7,695	7,695.2
Ex.5：12 Bays	13,213	13,213	13,212.6
Ex.6：13 Bays	14,338	14,338	14,338.8
Ex.7：14 Bays	15,289	15,971	15,289.0
Ex.11：15 Bays	17,705*	17,705	17,704.5
Ex.12：20 Bays	34,121*	**	33,462.0

Note: Distance in meters (M)
* The calculation time is too long; the list data are assumed the optimum among those so-far obtained
** The calculation time is too long to obtain the data.

Table 2: Comparisons of the calculation time for theEA, TP and GA

Examples	Algorithm		
	Enumeration	Two Phase	Generic
Ex.1：8 Bays	0.0	0.0	0.002
Ex.2：9 Bays	1.0	0.0	0.380
Ex.3：10 Bays	2.0	0.0	1.542
Ex.4：11 Bays	94.0	7.0	5.432
Ex.5：12 Bays	1,287.0	108.0	3.793
Ex.6：13 Bays	13,104.0	389.0	9.226
Ex.7：14 Bays	504,187.0	4,028.0	24.488
Ex.11：15 Bays	*	35,682.0	25.491
Ex.12：20 Bays	*	*	65.639

Note: time in sec.
* The calculation time is too long to obtain the solution.

C. Comparative Analyses of the Generic Algorithms and the Simulated Annealing Algorithms

The simulated annealing algorithm (SA) is based on the correlation between the annealing process of solid material and the process for solving the optimum combination problems. The declaration of parameters used in the annealing algorithm influences the solution quality to a great extent. In this paper, the results obtained by M.Y. Ku（1999）[12]using the annealing algorithm proposed for simulating wafer foundry operations were compared with the results obtained using the spine system for improving the facility layout in this research (Table 3).

Data obtained for all three examples using all four moving method shown in Table 3 show that the generic algorithm will lead to lower moving costs than the simulated annealing algorithm.

The average moving cost and standard deviation shown in Table 3 and Table 4 reveal that the generic algorithm is superior to the simulated annealing algorithm in obtaining better moving distance average, standard deviation and variation coefficient.

Additionally, Table 3 and Table 4 shows that the generic algorithm obviously has longer average calculation time in searching the optimum solution than the simulated annealing algorithm. Although the variation coefficients are 0.372 for the simulated annealing algorithm and 0.379 for the generic method without much difference, the results demonstrate that as the calculation time is concerned, the generic algorithm is inferior to the simulated annealing algorithm.

IV. CONCLUSIONS AND ECOMMENDATIONS

A. Conclusions:

When solving for the optimum facility layout for the spine arrangement in a wafer foundry factory, more bay numbers lead to longer calculation time and higher degree of difficulty. The generic algorithm along with Taguchi method has been implemented in this research for obtaining the optimum facility layout; this algorithm has been compared with the enumeration algorithm, the improved two-phase algorithm and the simulated annealing algorithm with the following findings:

1) The solution quality of the generic algorithm is closely related to the declaration of parameters. Using Taguchi method to solve the optimum level combination, the following results are obtained: 100 parents, 0.85 crossover rate, 0.103 mutation rate, 120 generations, partial corresponding mating and sequence-oriented mutating.
2) For cases with fewer than 20 bays, more than 96% solution quality can be achieved using the generic algorithm with less calculation time than the enumeration algorithm.
3) When the number of bays exceeds 10, the generic algorithm will yield better solutions than other algorithms tested because this algorithm is capable of finding the optimum solution based on simultaneous search of multiple points to avoid the pitfall of regional optimum

solution.

B. Recommendations

Recommendations for conducting future studies on implementing the generic algorithm to solve the facility layout problems for wafer foundry factories may include the following:

1) The study may be expanded to cover multiple-story buildings or multiple-target spine arrangements.
2) Other algorithms, e.g. Tabu algorithm, Ant algorithm and artificial network, etc. may be included such that the results obtained can be compared with those obtained in other relevant studies.
3) The planning of material handling in a wafer foundry factory may include some realistic restraints, e.g. pod number, number of temporary storage areas and material transportation time.
4) The current study has been carried out on a single shortcut in the middle of the central ceiling vehicle system; future studies may target the analyses and comparison of the cost and location of crossovers.
5) The minimization of material moving distance is the objective function of this study by assuming that there exists a linear relationship between the cost and moving distance without considering other relevant but un-quantifying information. Hence, some optimum solution obtained may not be appropriate bases for facility layout in the wafer foundry factory. Future studies should consider the addition of other relevant information such that more realistic solutions can be obtained.

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Table 3. Comparison of the Results obtained using the Simulated Annealing algorithms and the Genetic Algorithm

Algorithms		Simulated Annealing algorithms			Genetic Algorithm		
Bay No.	Handling direction	Optimal layout cost	Average of handling distance	Average of calculation time	Optimal layout cost	Average of handling distance	Average of calculation time
11	S.D.	3,520	3,637.3	2.885	3,463.5	3,474.4	10.476
	D.D.	2,206	2,272.7	2.614	2,180.5	2,185.9	15.784
	S.D+S	2,694	3,050.9	3.170	1,729.5	1,784.7	13.835
	D.D.+S	1,686	1,740.4	2.663	1,654.5	1,683.2	10.097
13	S.D.	15,543	16,726.1	3.645	15,467.0	15,597.8	19.306
	D.D.	8,162	8,458.7	5.585	8,084.0	8,115.8	17.200
	S.D+S	11,143	12,579.1	5.701	7,563.0	7,858.3	10.221
	D.D.+S	5,949	6,267.7	5.222	5,377.0	5,518.2	19.118
14	S.D.	3,044	3,199.5	5.236	2,973.5	3,085.1	33.872
	D.D.	1560.5	1,689.9	5.482	1,484.5	1,526.1	28.386
	S.D+S	2,153	2,498.2	6.595	1,442.5	1,502.9	26.548
	D.D.+S	1,159	1,274.0	6.056	1,034.5	1,113.9	29.214

N.B.: S.D: Single direction, D.D.: Double direction;
S.D+D: Single direction + shortcut, D.D.+S: Double Direction + shortcut

Table 4. Comparison of the Results on 10 material moving and moving time cases obtained using the Simulated Annealing algorithms and the Genetic Algorithm

Algorithms		Simulated Annealing algorithms				Genetic Algorithm			
Bay No.	Handling direction	handling distance		calculation time		handling distance		calculation time	
		Standard deviation	Coefficient Variation.	Standard deviation	Coefficient Variation.	Standard deviation	Coefficient Variation.	Standard deviation	Coefficient Variation.
11	S.D.	89.2	0.025	0.606	0.210	11.0	0.003	4.658	0.445
	D.D.	62.3	0.027	0.991	0.379	9.1	0.004	4.564	0.289
	S.D+S	205.5	0.067	1.025	0.323	50.8	0.028	4.307	0.311
	D.D.+S	46.6	0.027	1.158	0.435	13.8	0.008	5.767	0.571
13	S.D.	833.2	0.050	1.773	0.486	125.6	0.008	6.665	0.345
	D.D.	302.1	0.036	1.622	0.290	25.1	0.003	4.276	0.249
	S.D+S	1,189.7	0.095	2.374	0.416	215.1	0.027	4.348	0.425
	D.D.+S	315.2	0.050	1.959	0.375	150.7	0.027	8.455	0.442
14	S.D.	181.7	0.057	1.901	0.363	84.3	0.027	10.835	0.320
	D.D.	106.0	0.063	2.477	0.452	43.5	0.028	10.972	0.387
	S.D+S	163.7	0.066	2.538	0.385	40.5	0.027	9.538	0.359
	D.D.+S	96.8	0.076	2.077	0.343	41.6	0.037	11.887	0.407