A study on the spine layout for semiconductor manufacturing facility using simulated annealing

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Abstract
The construction cost for the wafer fab. of a semiconductor manufacturing is about NT$ 50 to 70 billions. Owing to the higher reentrant characteristics of the manufacturing process routing, the Automated Material Handling System (AMHS) and the layouts of the manufacturing fab. will determine the manufacturing efficiency at the earlier planning stage. The current wafer fab. layouts are their basis on the spine layout concepts. The spine layout is to allocate the material handling system at the center (like the spine of human body) of the manufacturing facilities, with the rest of the bays assigned to areas along the spine. This layout can reduce the material handling distance (time) and decrease the collision and vibration of the material handling systems.

The benefits of this concept can utilize the modularized function area to form the desired construction for use. A bay configuration arranged along a central spine and served by an AMHS is common for the layout and material handling system in the semiconductor wafer fabrication facilities. The purpose of adapting AMHS is to seek the best layout with low transportation cost and an efficient flow to reduce shock and vibration during the material handling, and the best use of manufacturing resources.

This paper applies the simulated annealing algorithm to the problem of spine layout, and considers four different material flow directions (clockwise, round way, clockwise with

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Journal of Statistics & Management Systems
Vol. 9 (2006), No. 3, pp. 591–612
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a short cut, and round way with a short cut) in the design process. The material handling cost and time are two evaluation criteria for this problem. Experiments were conducted to investigate the control parameters of the simulated annealing process so that the best solution and time can be found. The results show that the flow directions, cooling rate \( r \) and replicates \( L \) are significant factors.

**Keywords**: Spine layout, simulated annealing, semiconductor facilities.

1. Introduction

*Simulated Annealing Algorithms* (SA) and Spine Layout are two subjects of this research, whose objective is to apply Simulated Annealing Algorithms to Spine Layout.

Studies on spine layout in the past offered only the spine layout concepts, and had only limited discussion on the spine layout methods. Regarding researches of the application of SA to facility layout, most concentrated on ordinary facility layout with relatively few on spine layout. As a result, this research, by borrowing past experiences of facility layout of manufacturing system, attempts to find a layout model suitable for spine facility layout by combining the strengths of the simulated annealing algorithms to accomplish the spine facility layout design.

This research uses semiconductor fabrication facilities as a real example, and discusses the practicality as well as strengths and weaknesses of the spine facility layout. The traditional Heuristic Algorithms adopts the Greedy Strategy, only accepting the new status which can largely reduce the objective function. As a result, solutions and initial solution are related, and solutions are likely to fall into the Local Minimum so that the Global Minimum is difficult to obtain (Egles (1990)). In view of the above reasons and taking into consideration the time and quality of solution, a new heuristic algorithm is adopted to obtain the optimum solution or the approximate optimum solution.

Since the domestic economy changes rapidly, the modern facility planning is viewed as a dynamic one. The critical need of facility planning is its adaptability, so facilities need to have the capabilities of accommodating new functions. As far as the facility planning personnel is concerned, the idea of constant improvement is a must component in terms of facility planning cycle.
This research employs the SA heuristic algorithms to improve the spine facility layout to obtain the optimum solution or the approximate optimum solution to the layout method. It is expected to attain the following objectives:

1. To establish a spine facility layout analysis model.
2. To develop software enabling the SA to be applied to the spine facility layout, which will serve as reference for future teaching and researches.
3. To find the values of parameters in the SA through experiments, providing references for subsequent researchers in selecting parameters and number of levels in seeking solutions for similar problems.

2. Literature review

Tompkins introduced introduce the concept of spine layout in 1980 (Tompkins (1980)). The spine layout features a main aisle, with the design similar to a bone structure. All work bays (Functional Areas, Department, Cells or Bays) are located on both sides of the main aisle. In spine layout, the aisle in the middle can accommodate activities between work bays. The spine facility layout is particularly suitable for flexible manufacturing (Kusiak and Heragu (1987)). In terms of layout, it can effectively integrate two necessary features — modularity and flexibility (Tompkins and Spain (1983)). Tompkins proposed this type of layout concept but did not offer any method for designing the spine facility layout.

A plant’s layout design determines the practical effectiveness of combinations and the locations of work bays to achieve the optimal efficiency. The layout design has to connect all work bays, achieving the minimum transportation in the system (Afentakies et al. (1990)). The traditional layout method designs an inter-connecting network in facility layout (Muther (1973)), similar to dealing with problems in the detailed layout stage. Usher et al. (1990), Montreuil (1991), Riopel and Langevin (1991) suggest that the integration of network design and layout design can reduce the movement of products as well as personnel, and allocating sufficient space to each work bay. In heuristic algorithms, Montreuil and Ratliff (1989) once state that the Cut Tree method can be applied to the spine layout design. Houshyar and McGinnis (1990) offer one method, which establishes work bays on one aisle and adopts the concept of network. However, the issue remains that work bays have to be of
the same size, and this is not optimization. Beghin-Picavet and Hansen (1982) verify that the distribution of work bays of the same size along the aisle that minimizes the movement distance is a NP-complete issue, and use the motion-planning method to resolve the layout issue of 14 work bays of the same size.

Langevin et al. (1994) offer a two-phase solution, which is Heuristic Algorithms. It provides opportunities for designers to interrupt the layout process, whose objective is to find a layout with the least handling costs and investment costs. The handling costs are calculated by the following formula:

$$\sum_{ij} f_{ij} d_{ij}$$

where

- $d_{ij}$: cost of moving one unit from position $i$ to $j$,
- $f_{ij}$: flow intensity between two relative positions.

Most computer-assisted facility layouts (e.g., CRAFT, COFAD, etc.) use the distance between one center point to another without taking into consideration the network of the plant’s actual aisle. In spine layout, all material process is guided along the spine and accurately uses the actual distances between I/O (Input/Output) bays along the aisle network. Each work bay is allowed to have any number of I/O bays with flows limited to I/O stations. Intracell flow is the same as Intercell flow. We assume that the locations of I/O bays are along the spine layout.

Previous researches on semi-conductor manufacturing plants emphasized mostly the semi-conductor manufacturing and process, particularly in the materials management system, such as Cardarelli and Pelagagge (1995), and Carpenter (1993). They used executed information produced by the simulation method to analyze an existing fab. layout and material process system design. However, this method fails to provide relevant information on how to create or produce a good design, and how to combine design with layout to meet material processing system.

Researches have been conducted on the application of facility layout and material process design not specific to semiconductor manufacturing. For example, Dowlatshahi (1994), and Lacksonen (1994) both provide wide bone structure to integrate the designs of the manufacturing system. However, detailed design procedures of these bone structures were not specified.
Montreuil (1990) introduces a bone structure model to integrate layout and flow network design. Chhajed et al. (1992) offer a detailed flow network design for an existing facility layout. Yang and Peters (1995) use a space-filling curve method to resolve the facility layout design in a given Flexible Manufacturing System (FMS), and adopt the material loop (Loop) structure, adding short cuts to materials handling system loop manufacturing process to reduce material process costs with one step. The above methods are likely to be applied to semi-conductor plants layouts.

When Kouveliset et al. (1995) attempt to solve row layout problems, they assume equal areas. This approach may prove positive to some manufacturing system designs, but is not an adequate solution to work bay layout design since it fails to take into account the modification to work bay area size, material flow path and clear P/D point position.

Banerjee and Zhou (1995) design a direct and single-loop machine layout, which continuously forms flow sequences between machines and machine layout. It is an open-field type layout design but the layout structure cannot be pre-determined.

In order to produce a single loop materials flow path, Wu and Egbelu (1994) develop a phase according to which an ideal layout design determined under the assumption that the P/D point is the center point of every department. This phase arranges departments along the flow path, but it cannot resolve a specially structured fab. design. (1) This work bay is separated in two rows per. (2) P/D point may not be at the center point of the department. (3) Flow path may have short cuts.

Yang and Peters (1997) consider a material flow path, which not only covers special structure but also a semi-conductor manufacturing structure. They utilize the special structure along the spine to produce the work bay layout and materials system design. Both are applicable to the semi-conductor facility layout.

Tong (1991) and Tate and Smith (1995) develop a continuous architecture technology and use genetic search heuristic algorithms to individually attain solution to flexible work bay. The work bay structure design of the perimeter configuration spine layout allows one area block to include more than two work bays (see Figure 1).

Wang (1997) introduces improvement type algorithms to shorten the distances of moving wafers in the layout of a wafer plant. In terms of material flows, the features of AMHS facilities are adopted. By way of the two-phase approach, the switches between the departments of the same
areas and different areas are considered to achieve the minimum total moving distance. However, its material flows are only of single direction as well as two directions without emphasizing short cuts. The temporary storage area is at the center of the work bay.

![Figure 1: Perimeter configuration](image)

Hsu (1997) adopts applied group technology to undertake wafer plant layout planning, including the introduction of group technology theories, implementing the adjustment of group layout methods and conditions, simulating model structuring. From the practical point of view, the adoption of group technology has the following weaknesses.

1. Some machine platforms are in principle of the same machine group, but cannot be located close to each other due to other conditions, which reduces the effectiveness of group layout.

2. Owing to the separation of machine groups, the number of some machine platforms may need to increase.

3. When the product manufacturing processes vary greatly, the performance effectiveness of group layout may be less sound. The idea also emphasizes material flows of wafers.

Shiew et al. (1997) have introduced of the layout and materials handling of the existing semi-conductor plants, putting emphases on the impacts of semi-conductor plant features on their layout types as well as discussing the plant layout methods of semi-conductor plants.

Hong (1998) uses fuzzy theory to integrate quantity and qualitative factors in wafer facility layout in minimizing material handling costs and
taking into consideration of intangible costs. Hong also adopts the simulated annealing algorithms to search for the best layout of semi-conductor plant. However, in terms of material flows, the moving direction is one-way only without considering two-direction flows plus short cuts. Its temporary storage areas are located in the top right corner of each work bay.

Chang and Chieh (1998) introduced a semi-conductor plant layout according to process stages. In other words, the required machine platforms for continuous reprocess stages are concentrated in one area to reduce the moving activities across different zones. Their discussion is largely limited to the locations of machine platforms with the supplement of production schedule simulating software. Cycle time is used as the evaluation standard to assess the layouts of different semi-conductor plants. This assessment method is largely developed from pre-determined or existing environment of combinations. The production schedule simulating software is used to verify the differences due to different layouts employed by plants, and product manufacturing cycle time is used to search for the plan and subsequently undertake placement of machine platforms on site.

3. Model establishment

There are three features of spine layout which are of interest (Yang and Peters (1997)). First, materials process system may be modeling. If short cut single loop material flow path is adopted, then the locations of short cuts often have clear sequences. Second, in terms of work bay layout arrangement, each work bay needs to have a clear boundary with the central spine in the floor space so as to enter the auto materials transportation system. Third, the height of work bay normally covers the entire length of the facility. However, the heights of the two areas may differ. These design parameters are determined according to the surface layout of work bay and usable floor space. Therefore, detailed design parameters should be proposed before resolving layout problems.

Quadratic Set Covering Problem (QSCP) formula is a layout design problem (Bazarra (1975)). A spine type material process system structure can provide the correct layout design model. This research employs QSCP to distribute usable space and departments to access each work bay.

In spine type design layout (see Figure 2), the objective value is the minimum total handling distance. Some conditions of assumption
are different from the research assumptions witnessed in ordinary facility layouts. For example, the handling method between work bays is largely based on the central corridor in spine type facility layout. If the direction of movement in the central corridor is not taken into consideration, then the errors in the total distance algorithms must be quite significant.

Minimize

$$Z = \sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij}d_{ij}$$

where

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

Since a semi-conductor plant uses AMHS facilities, its materials handling directions will render the distance calculation method between bays different. This research uses spine type facility layout to discuss four material handling directions of the AMHS, i.e., clockwise, two directions, two directions plus one short cut, and clockwise plus one short cut, and conducts experiments to obtain more reasonable solutions.
Set model for spine layout

The idea of short cuts added to the AMHS in this paper is similar to that of Yang and Peters (1997). The QSCP model developed by Yang and Peters is used as the basis and applied to spine facility layout design problem. Furthermore, an Automated Material-Handling Systems (AMHS) design is provided together with short cuts. The mode is as follows:

Minimize \[ \sum_{i=1}^{N} \sum_{j=1}^{N} I(i)I(j) \sum_{k=1}^{I(i)} \sum_{l=1}^{I(j)} \varepsilon_{ij}u_{ij}\delta_{ikjl}\xi_{ik}\xi_{jl} \] (2)

Subject to \[ \sum_{k=1}^{I(i)} \xi_{ik} = 1 \quad \forall \, i \] (3)
\[ \sum_{i=1}^{N} I(i) \sum_{k=1}^{I(i)} \alpha_{ikt}\xi_{ik} \leq 1 \quad \forall \, t \] (4)
\[ \xi_{ik} \in \{0, 1\} \quad \text{for} \quad i = 1, \ldots, N \quad \text{and} \quad \forall \, k \in I(i) . \] (5)

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;
- \( \varepsilon_{ij} \) : unit handling charge from the \( i \)th bay to the \( j \)th bay;
- \( u_{ij} \) : the directed flow density from \( i \)th bay to the \( j \)th bay;
- \( \delta_{ikjl} \) : the flow distance from the \( k \)th replacement of the \( i \)th bay to the \( l \)th replacement of the \( j \)th bay;
- \( \xi_{ik} = 1 \) if bay \( i \) is assigned to its \( k \)th candidate location; otherwise it is equal to 0;
- \( \xi_{jl} = 1 \) if bay \( j \) is assigned to its \( l \)th candidate location; otherwise it is equal to 0;
- \( I(i) \) : the set of candidate locations of bay \( i \);
- \( k \) : index for candidate locations; \( k = 1, \ldots, |I(i)| \);
- \( \alpha_{ikt} = 1 \) 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 \( k \)th location.

In the above formula, equation (2) is the objective function of the best spine facility layout design; constraint (3) is to ascertain the correct replacement location representing all work bays; constraint (4) is to establish which area block is more likely to be occupied by at most one work bay in the final layout; constraint (5) describes in details the constraints on variables.
Assumptions and calculations

In concert with the features of semi-conductor plant facility layout and the improved spine facility layout, and to further avoid unnecessary widening of research scope and complications, the assumptions of the research are listed below.

- Material handling system is elevated.
- Material handling is of four types: single direction (clockwise or counter clockwise); two directions; clockwise plus one short cut; two directions plus one short cut.
- The temporary storage area is located at the center point of the exits of all work bays near AMHS.
- When work bays are located in the same zone, the distance between each work bay is equal to the distance between each temporary storage areas; in the event that work bays are located in the different zones, then the distance between work bays is the distance between each temporary storage areas plus the width of AMHS.
- Only inter-bay material transportation is considered.
- The shape of work bay is rectangular.
- The AMHS is used as boundaries between areas, i.e., the area above AMHS is the north zone (denoted by $N$) while the area below AMHS is the south zone (expressed as $S$). The width and length of both zones are the same.
- Work bay cannot be divided; the area of work bay cannot be changed.
- Located on the same floor.
- One side of each work bay in both zones has to be adjacent to AMHS.

This program is mainly derived from the Spine Layout Program (SLP-SA) developed under the Simulated Annealing Algorithms. Information input for the program is of the following three categories.

1. The width and length of plant area, the length and width of work bay area, the length and width of the area of the central corridor, the number of work bays, initial temperature, cooling rate, the number of repetitions, rule of stop and so forth.
2. The initial layout diagrams of different numbers of work bays.
(3) The flow quantity matrix between each work bay.

The output information from the program is as shown in Figure 3, which includes

(1) final layout diagram;
(2) SA search process curves and exchange process;
(3) initial costs, the optimal solution or the approximate optimum solution for costs.

Figure 3
Program output data

4. Experiment and outcome analysis

The typical SA process involves the control of temperature ($T$). In the gradual reduction of temperature, the search process enables the objective function to reach near-stable status, and at the same time objective function is approaching the optimal solution. Factors which may well affect qualities of solutions in the SA process are: variation in values of parameters and alteration of SA process. As a result, factors, such as the initial temperature, cooling rate, the number of repeated executions under the same temperature, in the SA plan have to be accorded with different levels. Through experiments and statistics analyses, it is expected to find suitable factors to achieve the best solution while incurring the least cost.

In order to prevent problems begging for solutions not limited to certain scopes, or in order to test whether some problems are more
sensitive to factors, this research includes different directions of material flows into the factors of experimental design. Since different directions of material flows will lead to different handling costs and time of program execution, the status of heuristic solution will be affected during the random process of SA.

The directions of AMHS under discussion of this research are clockwise, two directions, clockwise plus one short cut and two directions plus one short cut. The temporary storage areas are located at the center point of work bays near the central spine. Differences will occur in calculating the matrix of distances due to directions of material flows. Regarding the setting of values of factor levels in the simulated annealing algorithms, it is preferable to set values with relatively larger differences in addition to making references to researches by Kirkpatrick et al. (1983), Golden and Skiscim (1986), and Liao (1986).

**Experimental results and analyses**

This research conducts experiments to examine the material handling costs of the layout and time spent on program execution. SAS program is used to process the calculation with hypothetical significant level accorded to each factor significant level of 5% (Type I error). Variance analysis can reveal whether significant relationship exists between each factor and analytical results (time and cost) as per Tables 1 and 2. If significant relationship exists, then a further step is taken to establish the differences between each confidence level.

<table>
<thead>
<tr>
<th>Variance source</th>
<th>Degrees of freedom (df)</th>
<th>Sum square (SS)</th>
<th>Variance (MS)</th>
<th>F value</th>
<th>Pr &gt; F</th>
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<td>C</td>
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(Contd. Table 1)
## Table 2

### ANOVA analysis (time)

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### Notes.
- *: Significant difference
- $A$: Material flows direction, $B$: Initial temperature, $C$: Repeated times, $D$: Cooling rate

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### Table 2

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<tr>
<th>Variance source</th>
<th>Degrees of freedom (df)</th>
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<td>51,211,528,69</td>
<td>6,866,66</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Sum</td>
<td>7648</td>
<td>201,726,408,10</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

### Notes.
- *: Significant difference
- $A$: Material flows direction, $B$: Initial temperature, $C$: Repeated times, $D$: Cooling rate
Summary of variance analyses under Tables 1 and 2 is concluded in Table 3. Under the hypothesis of significant level of 5% (Type I error), different directions of material flows have significant impacts on costs and time. Different numbers of repetitions under a given temperature under the simulated annealing algorithms and different cooling rates also have significant impacts on target values. However, the initial temperature does not have significant influences on qualities of costs and time.

Table 3
Table of comparison of factors’ influences on qualities of research results

<table>
<thead>
<tr>
<th>Material flows direction (AMHS)</th>
<th>Initial temperature (T)</th>
<th>Times of the number of work bays (c)</th>
<th>Cooling rate (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influences of factors on time quality</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Influences of factors on costs</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Comparison of SA algorithms method and two-phase improvement type algorithms

The two-phase improvement type algorithms are intended to make improvement through the introduction of two phases. In the beginning, the initial layout diagram and work bay are input into the program, followed by the calculation of distance matrix and the total handling costs. Finally, the phase method is employed.

The bay exchange law of the two-phase improvement type algorithms method is in fact carried out only when costs are truly improved after such exchanges. However, the simulated annealing algorithm is an exchange process which accords higher costs to a given probability. Thus, theoretically speaking, it is not affected by the initial solution. By using the material handling costs as evaluation standards, the comparison and test of 11, 13 are 14 work bays are demonstrated in Table 4.

5. Conclusion and future research interests

(1) Conclusion

This research applies the Simulated Annealing Algorithms to spine facility layout, i.e., a structure where work bays are located along the central spine, and uses an Automated Material-Handling Systems design
Table 4
Comparison of improvement under the two algorithms

<table>
<thead>
<tr>
<th>Categories of directions of handling</th>
<th>Two-phase improvement type algorithms</th>
<th>Simulated annealing algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial handling costs</td>
<td>Final handling costs</td>
</tr>
<tr>
<td>Single direction</td>
<td>7,663.5</td>
<td>5,888.5</td>
</tr>
<tr>
<td>Two directions</td>
<td>5,033.5</td>
<td>4,374.5</td>
</tr>
<tr>
<td>Single direction + short cut</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Two directions + short cut</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>30,448.0</td>
<td>21,751.8</td>
</tr>
<tr>
<td>Two directions</td>
<td>17,711.2</td>
<td>14,337.8</td>
</tr>
<tr>
<td>Single direction + short cut</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Two directions + short cut</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>5,589.5</td>
<td>3,920.5</td>
</tr>
<tr>
<td>Two directions</td>
<td>3,233.5</td>
<td>2,444.5</td>
</tr>
<tr>
<td>Single direction + short cut</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Two directions + short cut</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Note:
- The data of the two-phase improvement type algorithms are taken from Wang (1997). The distance between two work bays is the distance from the center point of one work bay to the center point of another.
- The data of the simulated annealing algorithms are also taken Wang (1997). The distance between two work bays is the distance between the center point of the boundary adjacent to AMHS of a work bay (i.e., temporary storage area) and the center point of the boundary adjacent to AMHS of another work bay.
- The two-phase improvement type algorithms include algorithms on neither single direction plus short cut nor two directions plus short cut. Thus, no such data are presented in the two-phase improvement type algorithms. The simulated annealing algorithms plus short cut can save a great deal of handling costs.
in semiconductor fab. facilities. The structure of work bays provides many benefits for the semiconductor manufacturing environment. This method allocates manufacturing facilities to many work bays, with each bay sharing the same facilities, which enables materials to flow between work bays. Since semiconductor manufacturing process is of loop type, the central spine’s AMHS material handling system can effectively operate in the semiconductor manufacturing environment.

The structure of this type of work bays has a very simple and practical categorization system with manufacturing facilities of the same category located in the same work bay. Maintenance and repair work can be conducted often without interrupting the manufacturing process. The maintenance of aisle can divide the space of work bays and clean rooms. The contributions of the spine layout are the reduction in costs and simplification of the maintenance operation inside the fab. Although other layouts may achieve the same results, the spine layout provides many positive conditions for work bay designs. Therefore, the semiconductor industry gradually adopts this structure.

AMHS is an automated material-handling systems design in semiconductor fab. facilities, which connects auto I/O (Input/Output) system between work bays. It also achieves automated material Input/Output, reduces impacts and vibrations on materials during handling activities, and provides a clean production environment to reduce defective products and improve production capacities.

General computerized methods for facility improvement are adopted in ordinary industries. Researches on similar computerized facility layouts specific to semiconductor fab. industry are very rare. Since the manufacturing process of the semiconductor fab. industry is of loop type, material flows differ from ordinary industries. In terms of material handling system and directions of material flows in this industry, this research has developed a computer-assisted facility layout by using VB.

Regarding the spine facility layout constructed under this research, the solution is obtained by borrowing the strengths of the simulated annealing algorithms, which are subsequently compared with the two-phase improvement type algorithms. The conclusion of this research are as follows.

• When the simulated annealing algorithms is used to seek solution, although the solution may not be the optimum solution, approximate optimum or solutions relatively close to optimum may be
obtained in accordance with each problem type. The qualities of these solutions are better than their traditional counterparts. In dealing with a less optimum solution, the simulated annealing algorithms will accord to it a probability of acceptance, becoming the next feasible solution. This is a good heuristic solution.

- The simulated annealing algorithm is a “to retreat in order to advance” algorithm, which accepts larger values and thereby produces local minimum.

- The quality of the solution and the setting of parameters of the simulated annealing algorithms are closely related. The quality of the initial solution will not affect the quality of the final solution in SA. In this research, the levels of factors, such as directions of material flows, the number of repetitions and cooling rates, have significant impacts on costs and time.

- To place work bays along the central spine and use AMHS material handling system is the trend of design for facility planning in semiconductor plants. As a result, the spine facility layout is very suitable for semiconductor plants which demand high efficiency and provide many challenges. Moreover, it can improve the production efficiency to increase production, reduce semi-products, increase utilizations of tools, and reduce impact and vibration during handling.

- The idea of spine facility layout is particularly suitable for flexible manufacturing and large-scale production size. In terms of layout, it can effectively integrate the two major features, namely modularity and flexibility, and is also suitable for rectangular layout. Semiconductor fab. facilities are known for flexible and modular production, short product life cycle, great changes and loop production. In response to the uncertainties of economic cycle, the ideas of spine facility layout can meet the demands of semiconductor fab. facilities.

- The research results provide better understanding of the design of parameters of the simulated annealing algorithms, enabling the finding of the more stable and effective parameter design. The application of the parameter design to the simulated annealing algorithms leads to better quality solution.
(2) Recommendations and future research interest

This research applies the spine facility layout to semiconductor fab. facilities. The recommendations and future research interest thereof are summarized as follows.

- Other algorithms may be considered, such as Genetic Algorithms, Tabu Search, Fuzzy Neural Network and so forth, which can be compared and analyzed with the simulated annealing algorithms.
- The direction of material flows focuses only on four types: single direction (clockwise), two directions, two directions plus one short cut, and single direction (clockwise) plus one short cut. Subsequent researches may increase the number of short cuts and conduct comparisons of cost analyses.
- This research only takes into account a single floor layout in semiconductor fab. facilities and a single spine layout. Future researches may consider more floors and multi-objective spine layouts, such as $T$ type, $+$ type, $H$ type, $\square$ type or more complicated tree type multi-objective spine facility layout proposed by Tompkins and White (1984).
- The bay exchange law of the simulated annealing algorithms selects randomly the close solutions to undertake a pair exchange, which is likely to cause duplicated and ineffective exchanges. It is recommended that the exchange law may be modified to improve the effectiveness of SA.
- This research adopts the minimization of objective model to calculate the total moving costs, and assumes the linear relationship between costs and distances without paying regards to other relevant costs as well as non-quantitative data. Owing to this, the obtained optimum solution may not be the most suitable layout. It is recommended that subsequent researches may take into account relevant data to bring the facility layout estimate more closely in line with practical needs.

References


Received March, 2006