行政院國家科學委員會專題研究計畫成果報告

依據產出利潤函數選取半導體製造之最佳製程計畫
Using Throughput Profit Function for Selecting Manufacturing Process Plan in Semiconductor Industry

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一、中英文摘要

在考慮半導體之製程計畫評估及最佳製程計畫選取時，由於半導體製造業具有「高投資也追求高利潤」的產業特性，但是傳統上僅以總體成本為評量依據的製程計畫評估與選取方法似乎不能符合該產業的需求。為此，我們提出一個把產品產出利潤和生產效率等因素也加入考量的衡量指標–產出利潤函數(TPF)，並利用此指標進行半導體之製程計畫評估及最佳製程計畫選取模式。 這個模式裏包括有兩個主要的階段： 在第一階段，先利用生產線平衡法將生產同一產品的所有製程計畫中的各種優先次序關係分解出來，進而得到數個包含不同工作指派及不同工作站數使用的可行組合； 接著在第二階段裏，一個整數規劃模式被應用來選出擁有最高產出利潤值的製程計畫為最佳解。

關鍵詞：製程規劃、製程計畫的評估及最佳製程計畫的選取、產出利潤函數、半導體製造。

Abstract

In a task of process plan selection using workstations, manufacturing process plans have different precedence relationships, unequal operating times and so on. It is necessary to consider these factors in evaluation models. Due to the use of different machines and tools that would increase the line efficiency with additional cost and the semiconductor fabricators are strongly asking for high profit for every product, a traditional total cost is not a good measure for the selection of manufacturing process plans. Hence, a two-phase evaluation model using throughput profit for each manufacturing process plan is proposed. In the first step of the proposed method, the precedence relationships of the manufacturing process for each part are decomposed. Several feasible combinations with different numbers of workstations and different task assignment are generated using a line balancing method. Then, an optimization model with associated throughput profit for process parameters is used for choosing the manufacturing process plans.

Keywords: manufacturing process planning, process plans selection, throughput profit, and semiconductor fabrication industry.

二、計畫緣由與目的

Most semiconductor fabricators maintain a static process plan for each of their product even when multiple process plans are feasible to produce the same product. The existence of multiple manufacturing process plans and routing for a part provides a certain degree of flexibility in manufacturing systems. And, the use of a single process plan for a part robs the manufactures not only the production flexibility but also efficiency. This is especially true for the semiconductor industry. Therefore, how to select a set of manufacturing process plans and routing for different machines and tools of required parts to maximize such benefits then becomes an important issue to semiconductor industry. The development of flexible manufacturing systems which can respond to the demand for production efficiency, on-time delivery, and low cost while meeting the requisites of short product life cycles and high product varieties is recently the trend in manufacturing system designs [1,2]. The existence of multiple manufacturing process plans and routing for a part provides a certain degree of flexibility in manufacturing systems. How to select a set of manufacturing process plans and routing for different machines and tools of required parts to maximize such benefits then becomes an important issue. In this research proposal, we intend to present and propose a more reasonable evaluation criterion to assist the selection of appropriate manufacturing process plans for the semiconductor fabrication industry which is known as one of the most difficult environment for manufacturing process planning, and production planning and scheduling [3-6].

Process planning is defined as the systematic method for creating job instructions to produce or assemble a part or a product. For manufacturing systems, process planning is one of the important functions that generates a series of detailed operation instructions to transform raw materials to its desired product components according to design specification. Inputs of process planning procedure such as materials, geometrical features, dimensional sizes and tolerances are carefully analyzed to produce the appropriate production sequences with the use of available resources. Instructions such as required route, processes, process parameters and selection of proper machines and tools for production are necessary in manufacturing process plans. [8-12]

Tasks of production planning and scheduling are two critical functions of a manufacturing system as well as the selection of manufacturing process plan. For the production department, there are two main decisions that need to be made in the production planning stage. The first decision is called task assignment, which decides the assignment of machine tools to accomplish each operation on each scheduled part. The second is job sequencing, which decides what order the parts should be run. The efficiency of a manufacturing system relies heavily on proper task assignment and job sequencing. Hence, these two factors of production planning should also be considered in the selection procedures of manufacturing process plans. [13-17]

The recent methodologies proposed by researchers in the problem of manufacturing process plan selection intend to achieve the objectives of short processing time, low cost of removing the material, low scrap generation, higher tool life, etc. Several models have been proposed to solve the multiple manufacturing process plans selection problem and results of these works have made some contribution. However, these current methods do not consider the integration of the selection of manufacturing process plans and line balancing at the same time [18-23]. In general, only a number of fundamental elements carried by the process plans for a certain part are utilized as inputs for evaluation purposes. In these models, they try to achieve some or all of the following objectives: the total time to finish a set of parts is minimized, the total number of process steps is minimized, the total manufacturing cost is minimized, and the machine dissimilarity between process plan of different parts is minimized [16, 19]. Not only should we take these fundamental elements included in process plan into consideration but we also must integrate production-planning function and process plans together for a more reasonable solution.

The objective of this research is to solve the previously described problems in selecting manufacturing process plans that take into account the most important production control parameters. A NLPP type of approach is adopted to integrate considerations of process and production planning for selecting the best manufacturing process plans for semiconductor industry. When we are ready for entering the production planning stage, all possible plans of producing a part have been stored in the database and waited for the decision maker to select a plan that is suitable for the current shop floor status [14]. The following basic factors related with this selection problem are considered in the evaluation of alternatives: (1) the operation cost for each process plan; (2) the number of setup steps; (3) the operation precedence relationship for each process plan; (4) the cycle time for each process plan; (5) the number of workstations; (6) the production line efficiency; and (7) the target price of parts [7]. As this research continued, there will be more factors to be adding into the consideration, to formulate a more comprehensive throughput profit function for the process selection problem of semiconductor fabrication industry.

三、研究方法、結果與討論

A two-step procedure for the selection of process plans in semiconductor fabrication industry is proposed in this research. In the first step, the precedence relationships of process plans for each part are decomposed and the tasks of each process plan are assigned to several different fixed workstations. Applying the line-balancing requirement in this step then generates several feasible combinations with different number of workstations and different task assignment. Due to the fact that those manufacturing process plans to be selected have different precedence relationships, unequal operating time and so on, it is necessary to convert these factors into comparable figures. Hence, an optimization model with the value of throughput profit for each process plan is used for choosing the proper set of manufacturing process plans in the second step.

The proposed model is limited by the following assumptions.

(1) The time to perform a task in an operation sequence for a unit product is constant. Stochastic models with variant operating times are not considered in this paper.
(2) All input parameters, i.e., production planning period, the cost of setup, etc., in this approach are known.
(3) A process task cannot be further split into two or more workstations.
(4) Only one processing unit (machine with/without operator) is assigned to each workstation.
(5) The minimum required production rate or the maximum cycle time in a planning horizon for each part is given.
(6) All tasks that would be performed in a manufacturing process plan must follow their precedence relationships.
(7) There is sufficient space in each workstation to act as a buffer.

3.1 Decomposition of Precedence Relationship for Line Balancing

In order to translate the task precedence relationships into quantitative variables is a required task in the first step of the proposed approach. The assembly line balancing (ALB) method provides a useful tool to solve the constraints caused by precedence relationships. The objective of the assembly line balancing method is to optimize the production line performance. A well-balanced line could reduce the amount of work-in-process and increase the machine utilization [24, 25]. Traditionally, a mathematical model for solving a general ALB problem can be described as follows:

Solving the ALB Problem

$$Min \quad \sum_{i=1}^{N}\sum_{w=1}^{W} C_{iw} X_{iw} \ , \qquad (1)$$

$$\text{subject to} \quad \sum_{i=1}^{N} t_i X_{iw} \leq \quad Ct^* \quad ,$$

$$\text{where} \quad w = 1, \ldots, W; \qquad (2)$$

$$\sum_{w=1}^{W} X_{iw} = 1 \quad ,$$

$$\text{where} \quad I = 1, \ldots, N; \qquad (3)$$

$$\text{and} \quad X_{vb} \leq \sum_{j=1}^{b} X_{uj} \ , \qquad (4)$$

$$\text{where} \quad b = 1, \ldots, W \text{ and } (u, v) \in PR.$$

And, the notations used in ALB problem are given as follows:

N is the number of tasks in a process plan;
W is the number of workstations;
t_i is the operating time for task i;

$$X_{iw} = \begin{cases} 1, & \text{if task } i \text{ is assigned to workstation } w, \\ 0, & \text{otherwise} \end{cases}$$

C_{iw} is the cost coefficient of X_{iw};
C_t is the actual cycle time in a production-planning period;
C_t^* is the maximum cycle time in a production planning period;
PR is the constraints of precedence relationship.

There are several approaches that could solve the line balancing problems [23-28]. However, the objective of the proposed method is to find all feasible task assignments, which could satisfy the minimum production requirement.

Given the maximum cycle time (Ct^*), precedence relationship, and task operating time for each part, we can obtain the following information using the Ranked Positional Weight (RPW) method by Helgeson and Birnie [28]: (1) number of station, (2) production line efficiency, and (3) task assignment. The line efficiency rate can be calculated by

$$E = 100 \times \frac{\sum_{i=1}^{n} t_i}{Ct \times W} \ . \qquad (5)$$

3.2 Throughput Profit

The throughput profit (abbreviated as *TPF* in the following discussion) is defined as the total revenue from the parts we produce during a production planning period (*TR*) minus the total associated manufacturing cost (*TCp*):

$$TPF = TR - TCp \ . \qquad (6)$$

Generally speaking, the total revenue (*TR*) is defined as the target price offered to buyers (*Pp*) times the number of parts produced during a production planning period (*Np*), which is

$$TR = Np \times Pp \ . \qquad (7)$$

In the proposed method, we facilitate the concept of profit instead of cost when selecting manufacturing process plans. The general format of throughput profit for a manufacturing process plan can be obtained by the following procedures:

(1) Assuming that the production planning period (*Pt*) and the cycle time (*Ct*) obtained by the line balancing method have the same units (e.g., minutes), the total numbers of parts produced in one production period (*Np*) is:

$$Np = \frac{Pt}{Ct} \times E \ , \qquad (8)$$

Where E is the line efficiency rate obtained by Eq. (5).

(2) Two cost items are considered in the proposed method: the operational cost in each single workstation (Cw) and the cost of idle time caused by the production delay (Cd). After these costs of the associated workstation are determined, the cost of a certain workstation in one production period (TCw) can be obtained by

$$TCw = Cw + Cd \times (1 - E). \qquad (9)$$

(3) The manufacturing cost is composed of different cost elements in different production stages. Only those factors such as the operation and material cost for each part (Cp), setup cost for each process (Cs), and the cost of a certain workstation in one production period that are directly linked with the process plan are considered. Thus, the total manufacturing cost (TCp) can be defined as:

$$TCp = (Cp \times Np) + (Cs \times Ns) + (TCw \times W), \qquad (10)$$

Where Ns is the number of processing setup.

(4) Combining Eq. (8), (9), and (10) together, the desired throughput profit function for each process plan described in Eq. (6) can be written as:

$$TPF = \frac{Pt}{Ct} \times E \times (Pp - Cp) - (Cs \times Ns) - (Cw + Cd \times (1-E)) \times W \qquad (11)$$

3.3 The Selection of Process Plans

The problem in the second step of the proposed method can be formulated as a 0-1 integer-programming problem. The objective of this model is to maximize the throughput profit that is contributed by the cited process plan of each part. The objective function can be formulated as:

$$Max \sum_{i=1}^{N} \sum_{j \in P_i} \left[\left(\frac{Pt}{Ct_j} \right) \times E_j \times (Pp_j - Cp_j) - (Ns_j \times Cs_j) - (Cw_j + Cd_j \times (1 - E_j)) \times W_j \right] \times X_j \qquad (12)$$

$$\text{subject to} \sum_{j \in P_i} X_j = 1 \quad \forall i \in \{1,2,3,\ldots,N\}, \qquad (13)$$

$$\text{and} \qquad X_j \in (0, 1) \qquad (14)$$

The notations used in (12)-(14) are given as follows:

- i is the number of parts: $1, 2, \ldots, N$;
- j is the number of process plans;
- P_i is the set of process plans for part i;
- $X_j = \begin{cases} 1 & \text{if process plan } j \text{ is chosen} \\ 0 & \text{otherwise} \end{cases}$;
- Pt is the production planning period;
- Ct_j is the cycle time for process plan j;
- W_j is the number of work-centers for process plan j;
- E_j is set of production line efficiency for process plan j;
- Ns_j is the number of process setup for process plan j;
- Pp_j is the target price offered to buyers per product of process plan j;
- Cp_j is the cost per product for process plan j;
- Cs_j is the cost associated with production process setup for process plan j;
- Cd_j is the cost of idle time of production line delay for process plan j;
- Cw_j is the cost associated with work-center for process plan j.

The factors considered in the proposed method are the production planning period, the precedence relationship (i.e., cycle time, number of workstations, number of process steps), the target price offered by buyers for each part, the number of process setup and the rate of production line efficiency. Eq. (12) shows that a feasible process plan generated in the first step of the proposed method with the higher line efficiency or the higher target price and the lower manufacturing cost, (i.e., less number of workstations, less idle time and less number of processing setup) will have a better chance of being selected as the final solution. The constraint in Eq. (13) is used to make sure that exactly one process plan for each part i is selected. The second constraint in Eq (14) is used to maintain the integrity of the decision variable, X_j.

The procedures of the proposed method for the selection of manufacturing process plans are summarized as the following

[Step 1] *Line Balancing Process:*

(1.1) Obtain the maximum cycle time (Ct^*) for each part in a production planning period so that the throughput of each part can meet their demands.

(1.2) Set the given maximum cycle time (Ct^*) as a basic requirement; we can obtain the task assignment, number of workstations, and line efficiency rate by using the RPW method.

(1.3) If it requires more than one machine at the same workstation for a better line efficiency, then terminate this algorithm; if not, continue this algorithm.

(1.4) Determine whether the cycle time can be reduced without increasing current number of workstations. If the number of workstations increases, then stop. Go to procedure (1.5). If there exists a better cycle time, Ct, then generate a new solution for Ct and repeat this procedure until a task assignment with the best line efficiency rate has been found.

(1.5) Increase the number of workstations by 1 and go to procedure (1.3)

[Step 2] *Selection Process:*

(2.1) Calculate throughput profits (TPF) for all plans generated by [Step 1] using Eqs. (11) and (12).

(2.2) According to the Constraints (13) and (14), select the manufacturing process plan with maximal TPF as the final solution, which is:

$$\max_{\text{all plans}} \{TPF\} \Rightarrow \text{the selected manufacturing process plan.} \quad (15)$$

3.4 Implementation & Evaluation

In order to illustrate the usability and performance of the proposed method in selecting a manufacturing process plan for semiconductor industry, the same set of published example from Kusiak and Finke [20] and Bhaskaran [21] are used for demonstration. From the summarized result, the proposed method is not only capable to help evaluate manufacturing process plans and then select the most profitable one for production; it also can provide other useful parameters for further analysis. Besides, a set of engineering data that closely related to semiconductor manufacturing data are also used for implementation and evaluation purpose. The results of the second set of implementation also indicates that in the work center environment the proposed method has better performance in selecting manufacturing process plan when the manufacturing profit (or throughput profit) is the major concern for certain industry (such as semiconductor industry).

Due to limitation of length of this report, we are not able to put detailed information about these implementation examples and results. For those who are interested in this proposed method, we are glad to provide further information via e-mail or phone.

四、計畫成果自評

有關本計畫執行成果的評量，可依下列角度分別列述：

- 就研究內容與原計畫相符程度而言，它們在內容和精神上是完全相同的。
- 就達成預期目標情況來看，達成率也相當高，除原計畫中關於發展製程整合強化程序來降低所使用機器設備間之相異度的部份，因牽涉範圍比預期大出許多，加以相關資訊龐雜，造成時間不足、資料蒐集未臻完善等問題而暫未能完成外，其餘均已達成。
- 「以加入利潤為考量重點的產出利潤函數為製程選擇的工具，而非僅以成本為主要考量」是本研究之主要發現與貢獻，此一研究成果在學術上或應用上均有其價值。

- 至於本研究是否適合在學術期刊發表：本研究之先期研究成果已經於年前發表於國際學術期刊 Computers and Industrial Engineering [29]，現階段的研究結果也正在作實證資料補充和結構修改的工作準備向國內外工工相關學術期刊投稿。
- 有關加入「機器設備間之相異度」的考量以降低相異度並有效地壓低生產成本而提高產出利潤，將可更進一步提昇本研究計畫的學術及實用價值。 因此，我們將以此為本研究之後續研究方向，繼續發展使其更加完善。

五、參考文獻

[1] A. K. Sethi and S. P. Sethi. Flexibility in manufacturing: A survey. *Int. J. Flexibility Manufacturing Systems*, **2**, pp. 289-328, (1990).

[2] Y. Seo and P. J. Egbelu. Process plan selection based on product mix and product volume. *Int. J. Prod. Res.* **34**, pp. 2639-2655 (1996).

[3] L. M. Wein. Scheduling semiconductor wafer fabrication. *IEEE Trans. Semiconductor Manufacturing*. **1** (3), pp. 115-130 (1988).

[4] W. W. Wen and R. C. Leachman. An improved Methodology for real-time production decision at batch-process work stations. *IEEE Trans. Semiconductor Manufacturing*. **6** (3), pp. 219-225 (1993).

[5] P. K. Johri. Practical issues in scheduling and dispatching in semiconductor wafer fabrication. *J. Manufacturing Systems* , **12** (6), pp. 474-485, (1994).

[6] 莊達人，VLSI 製造技術，第三版，版立圖書，台北市(1997).

[7] L. F. Atherton and R. W. Atherton. Wafer Fabrication: Factory Performance and Analysis, Kluwer Academic Publisher, 1995.

[8] R. G. Askin and C. R. Standridge. *Modeling and Analysis of Manufacturing Systems*, John Wiely & Sons, New York, (1993).

[9] R. B. Chase and N. J. Aquilano. Production and Operations Management: Manufacturing and Service, 7th ed., Irwin, Chicago, (1995).

[10] T. C. Chang and R. A. Wysk. *An Introduction to Automated Process Planning Systems*, Prentice-Hall, Englewood Cliffs, (1985).

[11] P. M. B. Frank. *Manufacturing Planning and Control*, Elsevier, New York, (1990).

[12] H. C. Zhang and L. Alting. *Computerized Manufacturing Process Planning Systems*, Chapman & Hall, London, (1994).

[13] S. Ghosh and R. J. Gagnon. A comprehensive literature review and analysis of the design, balancing and scheduling of assembly systems *Int. J. Prod. Res.* **27**, pp. 637-670 (1989).

[14] N. E. Larsen and L. Alting. Simultaneous engineering within process and production planning. *Proceedings of Pacific Conference on manufacturing*, Australia, (1989).

[15] D. D. Bedworth and J. E. Bailey. *Integrated Production Control Systems*, John Wiely & Sons, New York, (1987).

[16] C. J. Lin and H. P. Wang; Optimal operation planning and sequencing: minimization of tool changeovers. *Int. J. Prod. Res.* **31**, pp. 311-324 (1993).

[17] J. Jiang and M. Y. Chen. The influence of alternative process planning in a job shop scheduling. *Computer and Industrial Engineering*, **25**, pp. 263-266, (1993).

[18] Q. Chen. and B. Khoshnevis. Scheduling with flexible process plans. *Prod. Planning & Control*. **4** (4), pp. 333-343, (1993).

[19] J. S. Noble and J. M. A. Tanchoco. Design justification of manufacturing systems: a review. *Int. J. Flexible Manufacturing Systems*, **5**, pp. 5-25, (1993).

[20] A. Kusiak and G. Finke. Selection of process plans in automated manufacturing systems. *Int. J. Prod. Res.* **26**, pp. 397-402 (1988).

[21] K. Bhaskaran. Process plan selection. *Int. J. Prod. Res.* **28**, pp. 1527-1539 (1990).

[22] N. Singh, Y. P. Aneja, and S. P. Rana. Multiobjective modeling and analysis of process planning in a manufacturing system. *Int. J. Systems Science*, **21** (4), pp. 621-630, (1990).

[23] H. C. Zhang and S. H. Huang. A fuzzy approach to process plan selection. *Int. J. Prod. Res.* **32**, pp. 1265-1279 (1994).

[24] A. L. Arcus. COMOSOL: Computer Method Of Sequencing Operation Of Assembly Lines. *Int. J. Prod. Res.* **4**, pp. 259-278 (1966).

[25] I. Baybars. A survey of exact algorithms for the simple assembly line balancing problem. *Management Science*, **32** (8), pp. 909-932, (1986).

[26] E. H. Bowman. Assembly line balancing by linear programming. *Operations Res.*, **18**, pp. 385-389, (1960).

[27] R. R. Levary and M. D. Renfro. Application of assembly line balancing techniques to installment lending operations of commercial banks. *Computers and Industrial Engineering*, **20**, pp. 105-109, (1991).

[28] W. B. Helgeson and D. P. Birnie. Assembly line balancing using ranked positional weight technique. *J. Industrial Engineering*, **12**, pp. 394-398, (1961).

[29] S. Y. Wei, C. C. Lo and C. A. Chang: Using Throughput Profit Function for Selecting Manufacturing Process Plan. *Computers and Industrial Engineering*. **32** (4), pp. 939-948, (1997).