Construct a Wafer Foundry System in Manufacturing Industry Using Heuristic Algorithms

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***Abstract*—The research combines two heuristic algorithms, COMSOAL and Priority rule-based algorithm, to design a production scheduling algorithm. Meanwhile it refers to dispatching rule and wafer start rule. Also base on the requirements and characters of wafer foundry companies, it designs proper capacity constraint model and wafer start rule to construct production planning system. Using simple, fast and flexible methods to generate reasonable and feasible production plans. The results of the research can give the wafer foundry companies several contributions. First, it shortens the execution time of generating a production plan. It improves the flexibility and efficiency of production planning. Second, the resolution of production plan is raised from the summary of manufacturing process and product type to full product name of order and demand allocation. It improves the resolution and accuracy of information analysis. Third, the planning period of wafer start plan is improved as well. Last, the frequency of production planning operation is improved from once a fortnight to once a week. The time interval is shortened.**

***Index Terms*—wafer foundry, production planning; heuristic algorithm, production scheduling, capacity constraint**

I. Introduction

The characters of their orders are large number but less volume. Their reactions to the boom are very fast. The actions of delivering urgent orders and canceling orders are usual. Base on the above reasons, the flexibility and reacting capabilities of the production planning of the foundry companies are more important [1], [2].

The researching object of the research is a small and middle wafer foundry company. Its foundry business is only for front chip manufacturing process, not including backend manufacturing process of assembler and testing. It faces the challenge of competitors and the frequent change character of its customer. But the production planning operation can't react to the fast change of market demand by the long run operation and insufficient planning frequency. And due to the insufficient product resolution and too small planning time bucket of production plan, it can't analyze different product mix and the change in short period. The result is influencing the accuracy of product and financial analysis [3], [4].

The research looks forward to solve the problem of this company, and meet the following target:

1. Use database to integrate the data of all planning systems for improving the efficiency of data exchange. Meanwhile apply high efficient heuristic scheduling algorithm to shorten the operating time of production planning. It can improve the overall planning operation's efficiency.

2. Design Simplified and reasonable static capacity model with the appropriate dispatching and wafer start rule. So that the system can use the model to conduct a detailed production plan for improving the resolution of planning time bucket. And plan and forecast a reasonable and realistic production target to meet the fab requirements.

3. Make wafer output can start with a stable's trend. Let fab can keep stable capacity loading. So that the overall capacity to achieve optimal utilization.

II. Manufacturing Production Operation

A. Manufacturing Process

IC manufacturing process mainly by the silicon wafer cleaning, oxidation, lithography, etching, ion implantation and diffusion, thin film deposition and back-lapping technologies. Manufacturing process over at least several hundred steps, therefore the manufacturing processes is manufactured one level by one level. The major component is transistor, the metal oxide semiconductor. Fig. 1 is shown the process flow and steps of the MOS transistor manufacturing process [5]-[7].

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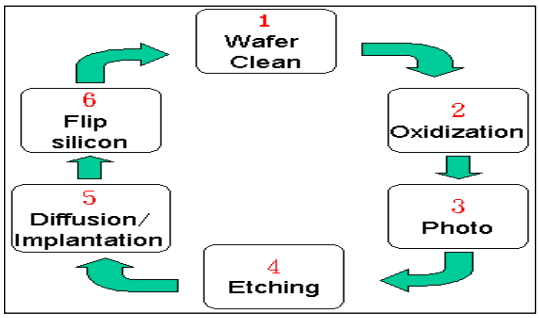


Figure 1. Flow chart of semiconductor manufacturing process

1) Production cycle time

The manufacturing production cycle time is the one of critical controlling parameters of wafer fab. Besides, due to the production cycle time of foundry fab and the time to market of customer product have the closed relation, it's the very important indicator of customer service satisfaction.

In calculating product production cycle time, it can be expanded to the indicators of different summarized levels. It's from operation step, manufacturing process stage, critical machine group and mask layer. Such as the Fig. 2 shows.

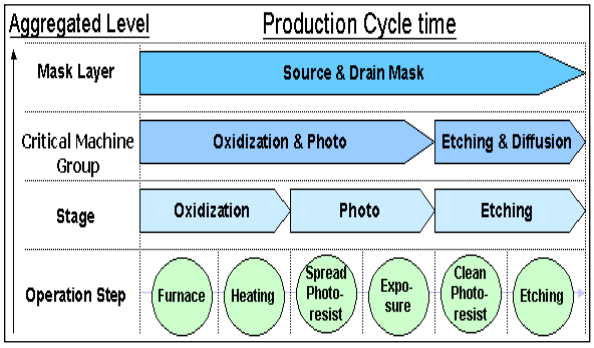


Figure 2. The diagram of production cycle time hierarchy of semiconductor manufacturing process

B. Heuristic Algorithm

Using the optimal approach to deal with the problem in the realistic world, it must adapter uncertain assumption to simplify the model. Besides, it will face the problem of inaccurate related required information. Therefore prefer to use non-optimal but reasonable solution to get the more right model. Instead of adapter optimal approach to resolved incorrect or overly simplified model [8], [9].

The complex problem or the solution has the restrictions of the time, it can't permit the precise solution. It can use heuristic algorithm to find the better feasible solution of the optimal problems. However, the processing time will be exponential growth according to the size of the problem. So when face the large scale and high uncertainty problems, the heuristic algorithm can be more flexible, fast, efficient method to build the approximated optimal solution. [10]-[13].

1) COMSOAL

Computer Method of Sequencing Operations for Assembly Lines (COMSOAL) was first declared by Arcus in 1966 and focused on the solution to assembly production line balance issue. Afterward there are many researches cite the algorithm to solve the problems of assembly production line balance domain. Compared COMSOAL and other resource allocation heuristic approached [14], [15]. They found that using COMSOAL can get better result than other approach in case of solving large sample problems. In applying COMSOAL to solve Resource Constraint Project Scheduling Problem (RCPSP), it will be through several repeatation of recurring procedures and operations to fast generate several feasible solution and choose the best result of them. The recurring procedure of the COMSOAL is as Fig. 3.

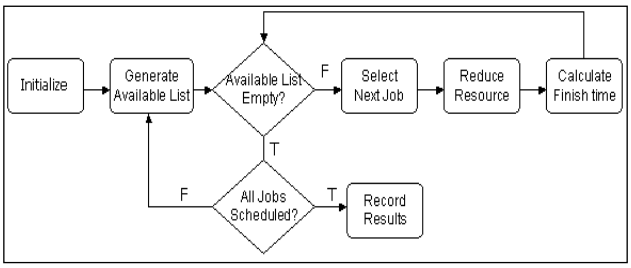


Figure 3. COMSOAL process flow chart

2) Priority rule-based algorithm

About the solution of Resource Constrainted Project Scheduling Problem (RCPSP), the Priority rule-based heuristic approach is frequently cited algorithm. [14]. Besides, the reason of the heuristic algorithm adaptered comprehensively is it can get the acceptable solution in reasonable processing time and cost.

According to the descriptions of literature researches, the process control of the algorithm has two portions, scheduling scheme and priority rule. The prior is used to construct one or more plans and the next is adapted to choose the next project activity to be assigned. The introductions are as the following [16]-[18].

1 Scheduling Scheme

According to forward planning, the basic principle is all the activities preparing to be scheduled and their prior activities must be assigned starting time.

2. Priority Rule

Priority rule is applied to select the next job to be scheduled. At every time point, the activities meet the scheduling condition might more than one. At the moment [19], [20].

3) Production operation flow

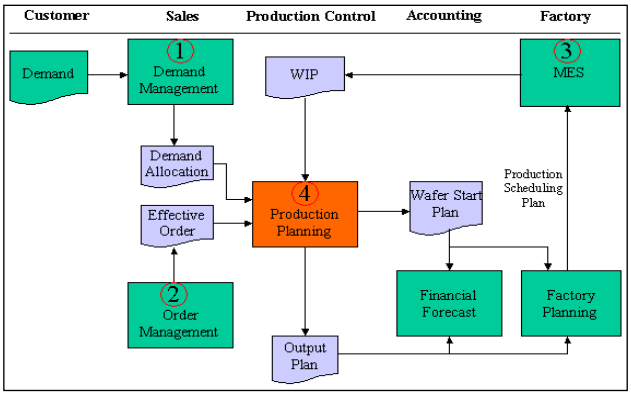


Figure 4. Original production planning operation process flow.

Then collect upstream report and paste into the worksheet manually to generate production plan for detail manufacturing scheduling and Accounting financial forecasting operation. Fig. 4 shows the original production planning operation process flow.

III. System Model and Algorithm Design

A. Production Process Design

For improving the problem of original production planning operation. The production planning system can directly load the data of upstream systems through database. It also can store the data for downstream systems in database and provide directly access. It can improve the operation efficiency and reduce the human error. The redesigned flow chart of the research is as Fig. 5.

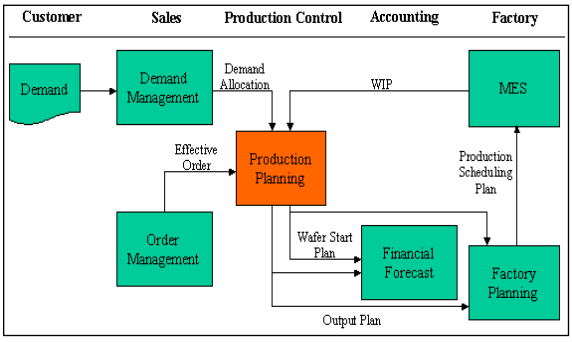


Figure 5. New design production planning operation flow chart

B. Production Algorithm

1) Demand scheduling sequence rule

Production planning operation is processing demand and supply problem. Due to the supply of specific period is limited, it must sort demands by proper rules and then using the resource to support the demand by order. The research adapters the priority rule of Priority rule-based heuristic algorithm to proceed the demand sorting for scheduling. The designed rules.

According to the characters of demand type and business strategy, finding out the priority rule items and give the selecting conditions. It also uses compound rule. The introductions are as the following:

1. Run Priority: The types and priorities are as superhot run, hot run and normal.
2. Commit date: According to the commit date of order and commit month of demand allocation, the demand with earlier commit will date get high priority.
3. Critical ratio: The formula is as the following. The smaller critical ratio will get high priority to reduce the risk of over the commit date.

$$\text{Critical Ratio (CR)} = \frac{\text{Commited Date - Current date}}{\text{Total Processing Remined Time}}$$

$$\text{Total Processing Remined Time} = \text{Remained Layes} * \text{Per Layer Cycle Time}$$

4. Demand type: The selecting sequence is re-wafer start order, non-wafer start order and pure demand allocation.
5. Order date: The order date shows the sequences of the order confirmation, so the earlier confirmed orders should get the high priority.

2) Production scheduling algorithm

The scheduling algorithm of the research combines two algorithms Priority Rule-based heuristic and COMSOAL. But considering the practical requirements of the wafer foundry fab's production planning operation. The partial steps of the algorithms need to be modified as the following:

1. Generate scheduling available list: the most of project activities have the order. In COMSOAL, when available list is empty, it must generate new list bases on the scheduled activities. So the first available list is including all the scheduling items.

2. Determine item's start time: In COMSOAL, the start time of next cycle is the earliest finishing time of current list plus current start time. As mentioned in item1, the scheduling items of production planning haven't absolute order. The process flow of the production scheduling algorithm designed by the research is as Fig. 6. The process logics and steps are explained as the following:

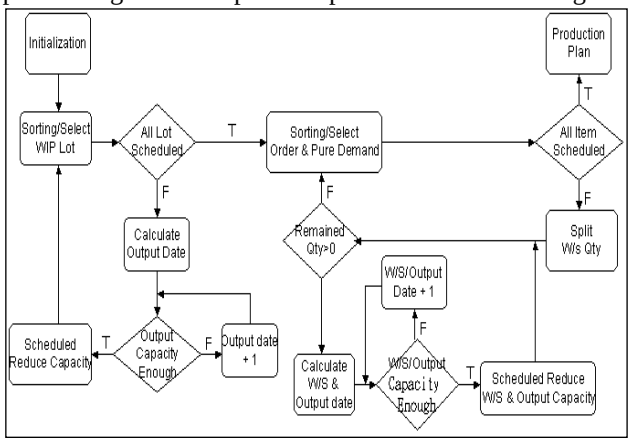


Figure 6. Production scheduling algorithm flow chart

1. Initialization
2. Scheduling the output of WIP and reduce output capacity
3. Sorting demand items with priority rules, getting these items by sequence and to execute the subsequent steps.
4. Calculating demand manufacturing time
5. Scheduling item bases on uniform allocation rule and capacity constraint

IV. System Implementation

A. System Architecture and Flow

The mission of production planning operation is to schedule demand and WIP to generate a feasible product plan. The system's functions not only need to set production parameter and capacity constraint, but also needs to load data from external systems. The system architecture is showed as Fig. 7.

The planning system has four modules. Its system process flow is as Fig. 7. Introduce the functions of the modules as the following:

1. Parameter setting module

2. External data loading and processing module
3. Production scheduling engine module
4. Production plan and report module

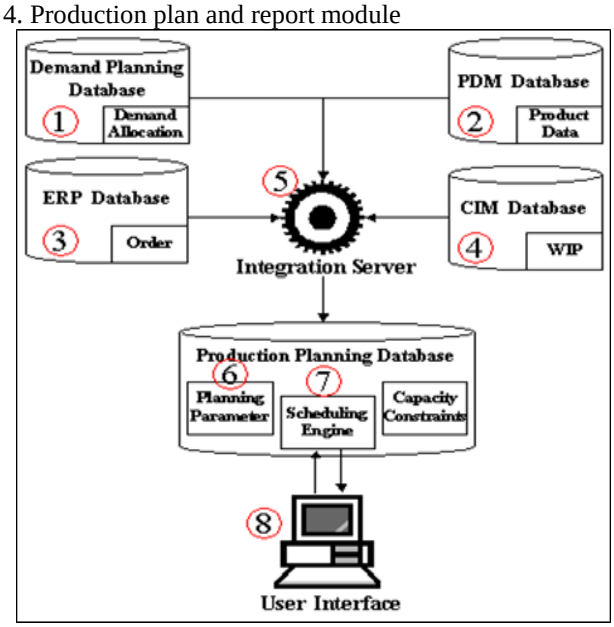


Figure 7. Production planning system architecture diagram

B. System Implementation

According to the functions of production planning processes and modules, the research proceed system implementation and introduce as the following.

1) External data loading and processing module

External data is loaded through data integration server, Data Stage and scheduled or launched by production scheduling interface. As Fig. 8 shows, Data Stage Server synchronously extracts external data and transfer into production planning database.

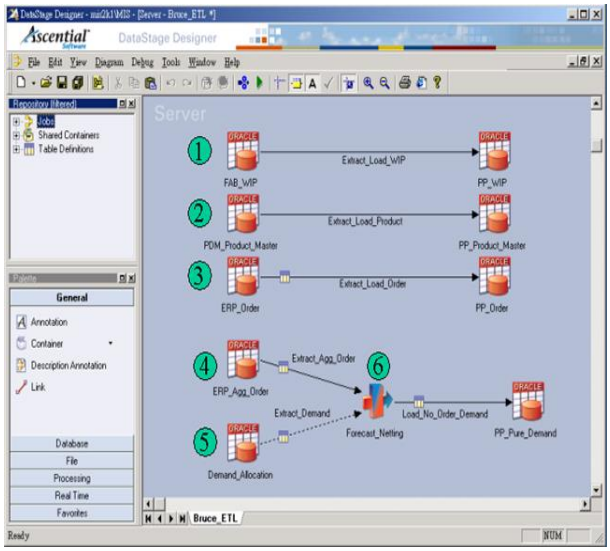


Figure 8. Data stage service interface

V. Experiment Test and Analysis

A. Testing Data and Experiment Design

The experiment testing data sources of the research is from a small and medium-sized semiconductor wafer foundry company. The testing data is from the actual data of the wafer foundry company. Then according to the design of the experiment with varied capacity utilization to generate several sets of simulating data for different planning period and monthly capacity utilization. The experiment design introduces as the following.

- Planning horizon: The period of Production planning horizon has the significant influence to the execution time and complexity of production planning. The research designs the period for 7, 10, 14 and 18 months to test the execution efficiency of the system.
- Monthly demand quantity: The testing design of customer demand uses a set of practical data and several sets of simulated demand as 30000, 40000, 50000 and 60000 pieces. The practical data as Table I.

TABLE I. Experient Testing Practical Data Set

Output Month / Demand Item	6	7	8	9	10	11	12
WIP	49,650	44,500	5,925	25	0	0	0
Not Wafer Start Order	0	8,700	15,800	746	425	0	0
Pure Demand	0	1,235	32,535	52,500	55,375	53,300	45,500
Monthly Quantity	49,650	54,435	54,260	53,271	55,800	53,300	45,500

B. Experiment Result Analysis

1) Production scheduling execution time

When proceeding testing cases, the same set data all executed three times to get the average execution time. The testing results are as Fig. 9. Base on the results, the longest execution time is the set of 18 months and monthly 60000 pieces. But the time is just 156 seconds. The executing speed is very fast to the whole production planning operation. Therefore when demand change, adjusting production planning parameter or changing capacity constraints, the system can generate a new plan in short time.

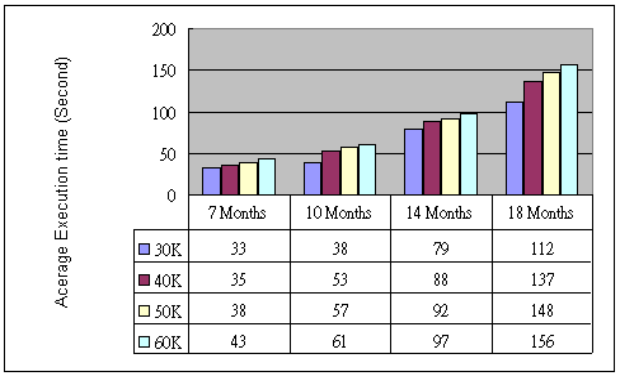
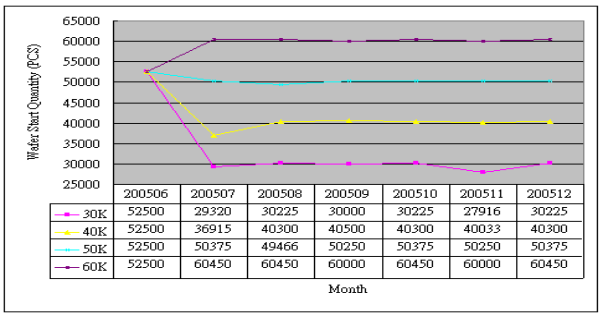


Figure 9. The statistics diagram of Production scheduling experiment

2) Wafer start plan

The production scheduling must satisfy the maximum of the daily wafer start plan under capacity constraints. It needs to assure the wafer start plan must be followed the plan of production planners. Figure 10 shows the monthly volume of wafer start and the diagram. According to the experiment testing data design, the data simulation are excluded in the analyzing target. Base on the result, wafer are linear and meet the targets of planner's setting.



	200506	200507	200508	200509	200510	200511	200512
30K	52500	29320	30225	30000	30225	27916	30225
40K	52500	36915	40300	40500	40300	40033	40300
50K	52500	50375	49466	50250	50375	50250	50375
60K	52500	60450	60450	60000	60450	60000	60450

Figure 10. Wafer start month plan diagram of Production scheduling experiment

C. Benefit Analysis

The motivation and purpose of the research is to solve the problems of the wafer foundry fab's production planning operation. The following analyses are to compare the planning results of the original and new planning systems.

1) Shorten production planning operation time

In original, the time of production planner generating a production plan is average 4.1 hours. The system of the research shorten. The execution speed is improved to 166 times. Leveraging integration server Data stage to extract, transform and load external data. The longest loading time is in 10seconds. Table II shows all the execution time of the testing castes in the experiment. Compare to the original operating time of production planning, it shows the execution performance of the research has significant improvement.

TABLE II. PRODUCTION PLANNING OPERATION EXECUTION TIME COMPARISION

planning Horizon (Months) / Monthly Capacity	7			10			14			18			Average		
	Old	New	Improved Times	Old	New	Improved Times	Old	New	Improved Times	Old	New	Improved Times	Old	New	Improved Times
30K	14400	43	335	14400	48	300	14400	89	162	14400	122	118	14400	76	191
40K	14400	45	320	14400	63	229	14400	98	147	14400	147	98	14400	88	163
50K	14400	48	300	14400	67	215	14400	102	141	14400	158	91	14400	94	154
60K	14400	53	272	14400	71	203	14400	107	135	14400	166	87	14400	99	145
Average	14400	47	307	14400	62	237	14400	99	146	14400	148	98	14400	89	163

2) Raise production planning resolution

So the resolution of the plan can detail to product name, such as Table III shows. The production cycle time, cost and price of the same technology and product type might have significant difference by different customer, application and complexity. Besides, based on detail production plan, it can aggregate to several dimensions and levels to proceed varied aspect analyses. All the departments related to production planning can improve the quality of planning and forecasting.

TABLE III. DETAIL PRODUCTION PLAN OF NEW PRODUCTION PLANNING SYSTEM

Customer	Demand	Part	WS_Date	Out_Date	Commited Date	Qty
445	FO07000754	XX0757H-NAZ1	06/01/2005	07/09/2005	08/01/2005	115
U048	U04806110753	XXH749A-NAZV	06/01/2005	06/07/2005	08/01/2005	25
A511	A51107040082	XXS763E0002D-NAZV	06/01/2005	07/22/2005	08/04/2005	50
514	FO07000678	XX1002A-NBZ1	06/01/2005	06/24/2005	07/30/2005	17
437	Demand-200507	XX0560	06/01/2005	07/10/2005	07/31/2005	10
J330	J33007040110	XXJ977D-T1NAZV	06/01/2005	07/07/2005	07/31/2005	50
514	FO07000748	XX0878A-NBZ1	06/01/2005	07/08/2005	07/31/2005	25
A511	A51107040082	XXS763E0002D-NAZV	06/01/2005	07/22/2005	08/05/2005	6
507	Demand-200507	XX1032	06/01/2005	07/07/2005	07/31/2005	25
437	FO07000691	XX0376G02A-TZHBZ1	06/01/2005	06/28/2005	07/25/2005	250
437	FO07000747	XX0086M02B-T1HBZ1	06/01/2005	06/30/2005	07/25/2005	50

VI. CONCLUSION

The research refers to a small and medium-sized wafer foundry company and focus on the problems of its production planning operation. According to the business characters and practical requirements, design and develop proper production planning model and heuristic scheduling algorithm. Apply the simple and fast solution to generate proper and feasible production plan.

The contributions of the research are as the following:

A. Shorten execution time of production planning operation. The time of generating a production plan is shortened from 4 hours to average 89 seconds. Improving planning speed to 163 times. The flexibility and efficiency of production planning is improved significant.

B. Raising the resolution of production planning. It's improved from aggregated plan by technology and product type to detail plan by product. Improve the resolution and accuracy of analyses.

C. Increase the frequency of production planning operation from once a fortnight to once a week. Shorten 50% of planning interval. In time to provide correct information for decision-making of high management.

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