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Resource grouping selection to minimize the maximum over capacity planning

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Abstract. This paper presents the capacity planning methodology for a testing process in a semiconductor industry. Due to numerous types of products and test resources, similar products and resources are grouped to reduce machine set up time, which also reduce delivery lead time. A mixed integer linear programming model is formulated to assign groups of products to groups of resources to minimize the maximum over capacity as the first objective and minimize the total processing time as the second objective. The results show the reduction of 12.8% over capacity and 7.8% set up time.

Keywords: Resource Grouping, Group Technology, Resource Selection, Capacity Planning

1. Introduction

Integrated circuits (ICs) are important components in electronic equipment. In the company, where is a case study, more than 1,000 types of ICs are requested from customers. The production process of ICs includes assembly, final test, and pack and ship as in Fig.1. Both assembly and final test processes indicate whether the product specifications meet the customer requirements. This paper focuses on a final test process, which is the bottle neck process.

Fig. 1 An integrated circuit process

The final test process of ICs uses machines and combinations of equipment including handlers, load boards and tools. Since machines and equipment are very expensive, the investment in the machines and equipment are limited. Therefore, the capacity planning that well utilizes all of these resources is required and proper final test scheduling is a key to succeed customer demand. To conduct the final test, machines and combinations of equipment must be selected to work simultaneously. Fig 2 illustrates types of machines and equipment. However, each product can be tested by more than one type of machines, handlers, load boards and tools with different processing times. There are multiple units of each type of resources.

Besides the capacity limitation, product mix, volume of demand, uncertain job arrivals and due dates increase the difficulty of the problem in the real setting. To reduce the problem complexity, group technology (GT) is applied to arrange equipment into combination sets. Each combination set includes one type of handler, load board, and tool. Also, GT is applied to assign products into families. All products that are in the same family must be able to be tested in the same types of machines and combination sets. Once

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product families and combination sets are obtained, a mixed integer linear programming model is used to assign product families to machines and combination sets to minimize the maximum over capacity and the total processing time.

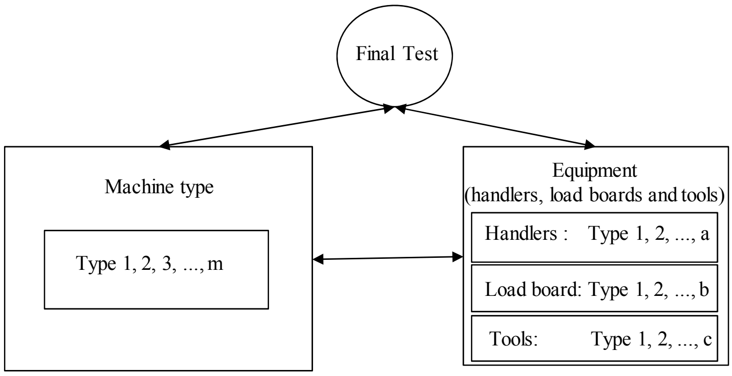

Fig. 2 Machines and equipment for the final test

2. Literature review

Group technology is a manufacturing philosophy that attempts to provide some of the operational advantages of the manufacturing cell layouts. Asoo [1] presented a group technology by designing a production process that adopted this manufacturing strategy. This study provided the advantages of cell layouts such as machine utilization is increased by the formation of components and product families. Saifallah [2] studied machine sharing in a cellular manufacturing system. This paper proposed a methodology to allocate machines between cells to increase machine utilization, increase production rate, and decrease flow time by considering set up time and demand constraints. Conditions under which the machine sharing led to cost reduction by reducing setup time. Machine sharing also resulted in a better distribution of the workloads among machines so that the possibility of having bottleneck is minimized.

Janiak et.al. [3] studied cellular manufacturing focusing on the dependent processing time. He classified *n* jobs into *g* groups and sequenced groups of jobs to minimize set up time by considering the due date of each group. Once groups of jobs are sequenced, jobs in each group are also sequenced considering the due date of each job. He also proposed a methodology to minimize resources assuming fixed set up time. The proposed methodology solved the problem in the polynomial time by using geometric techniques. The benefits of this method were a reduction in material handling and set up time, less work in process inventory and shorter flow time. Barbara [4] interested in the investigation of production planning using traditional shop and group technology. The performance measures were set up time, machine utilization, production rate, waiting time, and queue length. FCFS was used as a scheduling rule. Statistical analysis showed that the group technology provided better machine utilization, production rate, set up time. However, the traditional shop resulted in better waiting time, and queue length. Also, the group technology was proper for the problem with various job types

In the area of capacity planning and scheduling, Çatay et.al. [5] studied tool capacity planning in a semiconductor manufacturing. They considered the problem where demands were varied not only by types but also over time. They discussed the strategic level investment decision on the procurement of new equipment and aggregate level on capacity planning. They developed a mixed integer programming model to minimize the machine tool operation cost. The results showed that the methodology only solved the small industrial problems. Chen et al. [6] proposed a mathematical model to maximize profit considering limited capacities. To satisfy demand, sometimes over time production was needed, which affected the operating cost. The model tried to use the minimum over time to maximize profit. Similar to the previous paper, this methodology could be used for only small problem size. Ren-qian [7] studied capacity planning under stochastic production and uncertain demand. The main purpose was to determine the optimal equipment replacement schedule. To study the effect of stochastic factors on capacity planning, the model objective was to minimize the production and capacity expansion cost. The paper concluded that deterministic decisions may not establish a feasible production plan.

Due to a large amount of product types and resources in real setting, this paper proposes a 2-step capacity planning methodology. The first step tries to simplify problems by grouping products into families and grouping different types of equipment into combination sets. Then, next step proposes a mathematical model to match product families to groups of resources. The details of methodology are discussed in the next section.

3. Analysis and modeling

3.1 Resource and Product grouping methods

3.1.1 Resource grouping method

This step is applied to arrange handlers, load boards, and tools into combination sets. Therefore, a test process can select an equipment combination set instead of selecting each individual equipment. We consider all possibility of equipment groups. An example is illustrated in Fig.3. Given 3 types of machines, 6 types of handles, 11 types of load boards, and 11 types of tools, we can generate 16 combination sets. These combination sets are also matched with machine types, e.g., machine 1 can be applied with combination [H1, L1, T3], [H1, L4, T4], [H3, L5, T5], [H3, L5, T3], [H4, L6, T6], [H4, L6, T7], [H4, L7, T9]. Other combination sets are shown in Table 1. For the company resources, from 216 types of handlers, 330 types of load boards, and 327 types of tools, the total of 840 combination sets can be generated, which can be assigned to 6 different types of machines having multiple units in each type.

Table1. Example of machine and combination set grouping

Machine Type1	Machine Type2	Machine Type3
H1 L1 T3	H1 L1 T3	H5 L8 T7
H1 L4 T4	H1 L4 T4	H5 L9 T8
H3 L5 T5	H2 L2 T1	H5 L10 T10
H3 L5 T3	H2 L3 T2	H6 L11 T11
H4 L6 T6	H2 L5 T3	H6 L10 T10
H4 L6 T7	H2 L5 T5	H6 L10 T9
H4 L7 T9	H5 L8 T7	-
-	H5 L9 T8	-

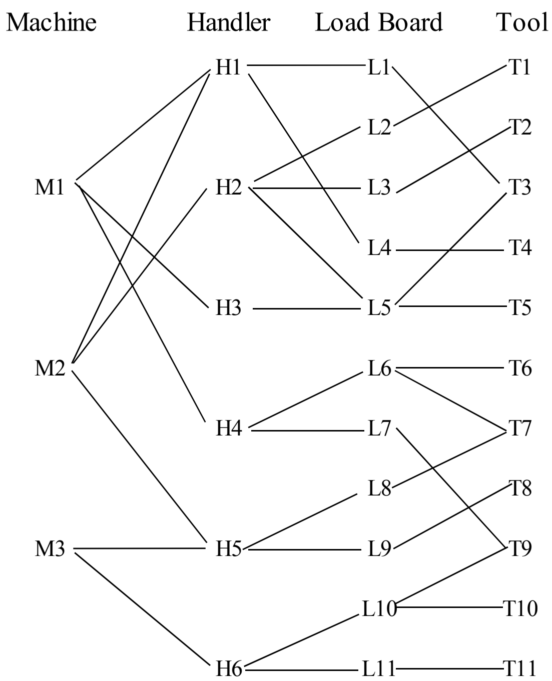

Fig 3. Machine grouping with equipment

3.1.2 Product grouping method

Due to the variety of product types, this step is done to group products with similar characteristics into product families. The attributes used to classify product include package sizes, lead types and hardware required to perform the final test including machine, handlers, load boards and tools. Fig. 4 shows examples of packages and lead types.

Packaging	Lead type
	Leg
	Ball

Fig 4 Example of lead types and packages

Fig.5 shows how products can be grouped. In the example, product family 1 is the family that contains 9" x 9" package size and ball lead type. The AA type of product belongs to 3 families, i.e., families 1, 2 and 3. The benefit of product grouping is to reduce machine and equipment set up time because all products in each family require the same equipment in the final test process.

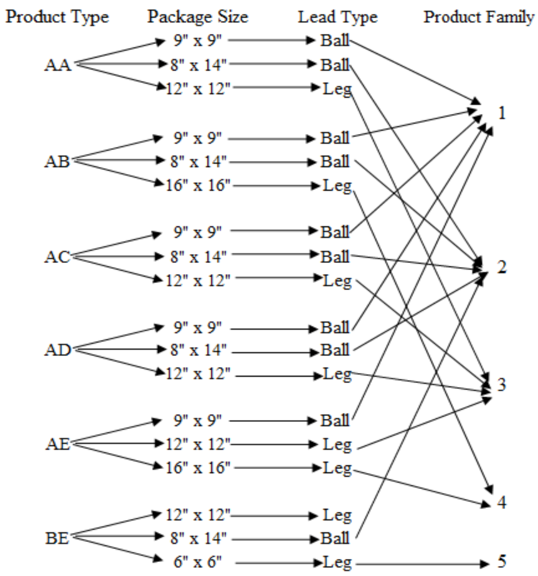

Fig.5 Example of prodcut grouping

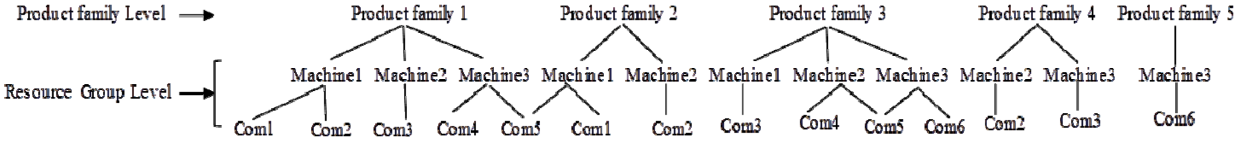

Fig. 6 An example of product family

Fig. 6 provides an example of product families and selections of their resources. However, from the customer demand, there are 545 product types which can be grouped into 65 families. Generally, there are 2 types of product families

1. Unshared resource product family: the product family that can be tested with specific machine and combination set such as product family 5 in Fig.6, which can be tested only on machine 3 and combination set 6.

2. Shared resource product family: the product family that can be tested by more than one machine type and combination set such as product families 1-4 in Fig.6. Product family 1 can be tested on machine 1 with combination sets 1or 2, machine 2 with combination set 3 or machine 3 with combination sets 4 or 5. With different machines and combination sets, the processing times are different.

3.2 Resource selection

From the previous section, since unshared resource product family can be tested on only one type of machine and equipment combination set, we allocate the required machine and combination set to this type of family first. For shared resource product family, more than one machine type and combination set can be selected. Each alternative may result in different processing time. In this case, a mixed integer linear programming model is formulated to allocate resources to product families. The main objective of the model is to minimize the maximum of over capacity resource in order to obtain the capacity plan that all test processes are completed within the standard working hours. In case that all tests can be performed within the standard working hours, the next objective is to minimize the total processing time as in (1).

Parameter

$I = \{1..p\}$ The number of product families to be tested

$J = \{1..n\}$ The number of types of combination sets used to test the product family

$K = \{1..m\}$ The number of types of machines

$Allow_{ij} = \begin{cases} 1 & \text{if combination } j \text{ can be tested for product family } i \\ 0 & \text{otherwise} \end{cases}$

$Demand_i$ Demand of product family i

$Cbavai_j$ The number of combination type j

$Macvai_k$ The number of machine type k

$Time_{ij}$ The processing time to test 1 unit of product family i using combination type j

$TotalHours$ The planning duration

M A big number

Decision Variables

$Passign_{ijk}$ The amount of product family i is assigned to combination type j and machine type k

$OverCap_k$ The number of hours of over capacity on machine type k

$Cassign_{jk}$ The number of type j combination that is assigned to machine k

T_k The processing time of machine k

$MaxOverCap$ The maximum over capacity of machine

Based on the above assumptions and definitions, the model of our problem can be formulated below:

$$Minimize\ Z \quad = MaxOverCap * M + \textstyle\sum_K T_k \tag{1}$$

Subject to

$$Passign_{ij} \leq allow_{ij}\, M \qquad \forall i \in I, \forall j \in J \tag{2}$$

$$\textstyle\sum_K \sum_J Passign_{ijk} = Demand_i \qquad \forall i \in I \tag{3}$$

$$\textstyle\sum_K Cassign_{jk} \leq Cbavai_j \qquad \forall j \in J \tag{4}$$

$$\textstyle\sum_J Cassign_{jk} \leq Macvai_k \qquad \forall k \in K \tag{5}$$

$$(\textstyle\sum_J \sum_I Passign_{ijk}\ x\ Time_{ij}) - TotalHour\ x\ Macvai_k \leq OverCap_k \qquad \forall k \in K \tag{6}$$

$$(\textstyle\sum_J \sum_I Passign_{ijk}\ x\ Time_{ij}) - \sum_J TotalHour\ x\ Cassign_{jk} \leq OverCap_k \qquad \forall k \in K \tag{7}$$

$$OverCap_k \leq MaxOverCap \quad \forall k \in K \tag{8}$$

$$\textstyle\sum_J \sum_I Passign_{ijk}\ x\ Time_{ij} = T_k \qquad \forall k \in K \tag{9}$$

$$Passign_{ijk} \geq 0 \qquad \forall k \in K, \forall i \in I, \forall j \in J \tag{10}$$

$$OverCap_k \geq 0 \qquad \forall k \in K \tag{11}$$

$$Cassign_{jk} \geq 0 \qquad \forall k \in K, \forall j \in J \tag{12}$$

$$T_k \geq 0 \qquad \forall k \in K \tag{13}$$

$$MaxOverCap \geq 0 \tag{14}$$

Constraints in (2) specify that product familiy *i* can be assigned to combination set *j* only if we can use combination set *j* to test product family *i*, which is predetermined in $allow_{ij}$. Constraints in (3) are demand constraints. Constraints in (4) limit the number of each type of combination set that are assigned to all machines to be less than or equal to the total number of that type. Constraints in (5) limit the number of combination sets that are assigned to each type of machine to be lower than or equal to the number of machines of that type. Constraints in (6) and (7) determine the over capacity of each machine. Constraint (8) calculates the value of the maximum over capacity. Constraints in (9) determine the total processing time in each machine. Constraints in (10) – (14) are used to force all decision variables to be non-negative.

4. Results and conclusion

Due to a large amount of product and resources, in this paper, we explore the effect of product and machine grouping on the performance of group technology. From the company data, there are 545 types of products, which can be grouped into 65 families. In term of resources, 216 handlers, 330 load boards, and 327 tools are grouped into 840 combination sets that belong to 6 types of machines. Resources including machines and combination set must be selected to different product families to balance their workloads and reduce the amount of over capacity. In case that all demand can be satisfied within resources' capacities, the decrease of total processing time is required. A mixed integer linear programming is formulated as a decision making tool. The result shows 12.8% over capacity reduction from the current capacity planning of the company and 7.8% set up time reduction because we process product group by group, which reduces set up time significantly.

This paper proposes the methodology to select resources for each product family, which is one step of planning. However, in the next step, we need to sequence products that belong to each machine in order to complete demands within their due dates.

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