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# Optimal Resource Configuration and Allocation Planning Problem for Bottleneck Machines and Auxiliary Tools

Yin-Yann Chen, Tzu-Ling Chen

***Abstract*—**This study presents the case of an actual Taiwanese semiconductor assembly and testing manufacturer. Three major bottleneck manufacturing processes, namely, die bond, wire bond, and molding, are analyzed to determine how to use finite resources to achieve the optimal capacity allocation. A medium-term capacity allocation planning model is developed by considering the optimal total profit to satisfy the promised volume demanded by customers and to obtain the best migration decision among production lines for machines and tools. Finally, sensitivity analysis based on the actual case is provided to explore the effect of various parameter levels.

***Keywords*—**Capacity planning, capacity allocation, machine migration, resource configuration.

## I. Introduction

THE semiconductor packaging and testing industry is characterized as a flow-line environment. The operating procedure of this industry indicates that die bond (DB), wire bond (WB), and molding (MD) stations are bottlenecks in the manufacturing process. Consequently, capital expenditure on equipment for the DB, WB, and MD stations results in high purchasing cost. In machine utilization, the limitations of machine type and product category affect the output per hour. In such a multi-factory and multi-line environment, demand uncertainty and inappropriate production planning result in wasteful or insufficient machine capacity in all lines. Therefore, this study investigates the DB, WB, and MD stations in the semiconductor packaging and testing industry.

The best resource configuration and capacity allocation decision in the semiconductor packaging and testing industry can effectively utilize all resources in all production lines, as well as assist planners in reducing the readjustment of the production scheduling to efficiently accomplish order allocations as a response to substantial changes in demand. Such a decision can also indirectly reduce the migration cost of machines and tools. Therefore, this study aims to investigate the resource allocation and migration planning problem to address the current challenges faced by the semiconductor packaging and testing industry.

Karabuk and Wu [1] state that capacity planning can be described as an iterative process characterized by the following main components: (1) capacity expansion in the context of projected product demand to identify the required manufacturing technologies and their capacity levels to be physically expanded or outsourced during the planning period; and (2) capacity configuration to determine which facility is to be configured with which technology mix. The overall objective is to establish a revenue model based on strategic demand planning, which blends demand forecasting and proactive market development strategies. This objective can be viewed as meeting projected demands with minimized total costs.

Chen et al. [2] present a capacity allocation and expansion problem of thin film transistor–liquid crystal display manufacturing in the multi-site environment. The objective is to simultaneously seek an optimal capacity allocation plan and capacity expansion policy under single-stage, multi-generation, and multisite structures. Capacity allocation decides on profitable product mixes and allocated production quantities of each product group in each production site. Capacity expansion is concerned with determining the timing, types, and sizes of capacity investments, particularly in acquiring auxiliary tools [3]. The foundry is an industry whose demand varies rapidly and whose manufacturing process is complicated. Chen, Chen and Liou [4] explore issues on midterm capacity planning for an increment strategy on the number of auxiliary tools, such as "photo mask," to increase production flexibility. The related decisions include how to appropriately allocate the forecast demands of products among multiple sites and how to decide on the production quantities of products in each site customer-confirmed orders are received [5].

## II. Resource Configuration and Allocation Planning Problem

### *A. Characteristics of Capacity Planning of the Semiconductor Packaging and Testing Industry*

This study aims to determine machine migration, tool migration in all production lines, resource configuration, capacity allocation, and product flow to achieve net profit maximization.

#### 1. Resource Configuration

The manufacturing process entails that a product should sequentially go through the DB, WB, and MD stations for assembly-line production. The product considers the machine type in resource configuration during the DB and WB stages. However, three resources, namely, machine type, tool type, and

Yin-Yann Chen is with the Industrial Management Department, National Formosa University, Yunlin 632, Taiwan, R.O.C. (phone: +886-5-6315716; fax: +886-5-6311548; e-mail: yyc@nfu.edu.tw).

Tzu-Ling Chen is with the Industrial Management Department, National Formosa University, Yunlin 632, Taiwan, R.O.C. (e-mail: tzuling @gmail.com).

material category, are considered in the MD stage.

2. Product Flow

This study disregards defective products and only considers production through the three sequential stages. Moreover, product flow balance must be maintained in the production line. Thus, the total product input must be equal to the final total output. For example, the product input for product 1 is 1,000 units. Furthermore, 400 and 600 units are produced in lines 1 and 2, respectively. After production through the three sequential stages, the final total output remains 1,000 units.

3. Capacity Allocation

The capacity planning for all received orders is executed based on the current existing resources in all production stages. A product is not limited to the same production line during the entire production process; that is, a product can be manufactured in the different lines through three production stages. For example, a company has two lines if the input of product 1 is 1,000 units. We take line 1 as an example. First, 400 units are manufactured in the DB station using machine *k1* and 600 units using machine *k2*. Thereafter, 400 units are manufactured in the WB station by using machine *k2* and 200 units using machine *k3*. Finally, 200 units are manufactured in the MD station by using resource configuration *k1*+*n1*+*m4* and 300 units using *k2*+*n2*+*m4*. Thus, 500 units of product 1 can be made after the three production stages for this product are completed sequentially in line 1. The remaining 500 units are allocated to all production stages in line 2 for manufacturing.

4. Machine and Tool Migration

The presence of several production lines and machines with different technological capability in a company results in varying production capacities of all lines. Machines can be moved to all lines in each production stage, and tools can be moved to all lines in the MD stage based on the total number of available machines and tools.

### *B. A Mathematical Programming Model for Capacity Planning Problem*

1. Indices

- $c$ = customer ($c$ = 1, 2,…, $C$ ).
- $i$ = product type ($i$ = 1, 2,…, $I$ ).
- $l$ = production line ($l$ = 1, 2,…, $L$ ).
- $s$ = production stage ($s$ = 1, 2,…, $S$ ).
- $j$ = resource configuration ($j$ = 1, 2,…, $J$ ).
- $m$ = material type ($m$ = 1, 2,…, $M$ ).
- $k$ = machine type ($k$ = 1, 2,…, $K$).
- $n$ = tool type ($n$ = 1, 2,…, $N$ ).
- $t$ = time period ($t$ = 1, 2,…, $T$ ).

2. Parameters

- $de_{ict}$ = the demand quantity of customer $c$ for product $i$ in time $t$.
- $pr_{ict}$ = sales price of customer $c$ for product $i$ in time $t$.
- $kl_{lsk}$ = initial amount of machine $k$ in line $l$ at stage $s$.
- $ku_{ls}$ = maximum number of machines in line $l$ at stage $s$.
- $ks_{ijsk}$ = required work hours of machine $k$ used at stage $s$ for manufacturing a unit of product $i$ with resource configuration $j$.
- $ka_{sk}$ = available work hours of machine $k$ at stage $s$.
- $kb_{ll's}$ = machine migration capability from line $l$ to $l'$ at stage $s$.
- $nl_{lsn}$ = initial amount of tool $n$ in line $l$ at stage $s$.
- $nu_{ls}$ = maximum number of tools in line $l$ at stage $s$.
- $ns_{ijsn}$ = required work hours of tool $n$ used at stage $s$ for manufacturing a unit of product $i$ with resource configuration $j$.
- $na_{sn}$ = available work hours of tool $n$ at stage $s$.
- $nb_{ll's}$ = tool migration capability from line $l$ to $l'$ at stage $s$.
- $mq_{smt}$ = total available quantity of material $m$ at stage $s$ in time $t$.
- $ms_{ijsm}$ = consumption ratio of material $m$ for manufacturing a unit of product $i$ at stage $s$ with resource configuration $j$.
- $tf_{ijs}$ = production capability of product $i$ at stage $s$ with resource configuration $j$.
- $tb_{lsl'(s+1)}$ = transportation capability from line $l$ at stage $s$ to line $l'$ at stage $s+1$.
- $vc_{iljs}$ = production cost for manufacturing a unit of product $i$ in line $l$ at stage $s$ with resource configuration $j$.
- $kc_s$ = machine migration cost at stage $s$.
- $nc_s$ = tool migration cost at stage $s$.

3. Decision Variables

- $KQ_{lskt}$ = the number of machine $k$ for line $l$ at stage $s$ in time $t$.
- $KM_{ll'skt}$ = the migration number of machine $k$ from line $l$ to line $l'$ at stage $s$ in time $t$.
- $NQ_{lsnt}$ = the number of tool $n$ for line $l$ at stage $s$ in time $t$.
- $NM_{ll'snt}$ = the migration number of tool $n$ from line $l$ to line $l'$ at stage $s$ in time $t$.
- $XQ_{iljst}$ = production amounts of product $i$ with resource configuration $j$ for line $l$ at stage $s$ in time $t$.
- $RQ_{iljsl'j'(s+1)t}$ = transportation amounts of product $i$ from line $l$ with resource configuration $j$ at stage $s$ to line $l'$ with resource configuration $j'$ at stage $(s+1)$ in time $t$.
- $SQ_{ict}$ = sales amounts of product $i$ for customer $c$ in time $t$.
- $SL_c$ = service level for customer $c$.

4. Objective Function

$$
\begin{aligned}
&Maximize \\
&\sum_i \sum_c \sum_t \left( pr_{ict} \times SQ_{ict} \right) \\
&-\sum_i \sum_l \sum_j \sum_s \sum_t \left( vc_{iljs} \times XQ_{iljst} \right) \\
&-\sum_l \sum_{l'} \sum_s \sum_k \sum_t \left( kc_s \times KM_{ll'skt} \right) \\
&-\sum_l \sum_{l'} \sum_s \sum_n \sum_t \left( nc_s \times NM_{ll'snt} \right)
\end{aligned}
\quad (1)
$$

It aims to obtain the optimal capacity planning decision to seek the maximization of net profit.

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5. Constraints

- Machine migration balance constraints

$$KQ_{lsk0} = kl_{lsk} \quad \forall l,s,k \tag{2}$$

$$KQ_{lskt} = KQ_{lsk(t-1)} - \sum_{l'} KM_{ll'skt} + \sum_{l'} KM_{l'lskt} \quad \forall l,s,k,t \tag{3}$$

$$KQ_{lskt} \le ku_{ls} \quad \forall l,s,k,t \tag{4}$$

$$KM_{ll'skt} \le M \times kb_{ll's} \quad \forall l,l',s,k,t \tag{5}$$

- Tool migration balance constraints

$$NQ_{lsn0} = nl_{lsn} \quad \forall l,s,n \tag{6}$$

$$NQ_{lsnt} = NQ_{lsn(t-1)} - \sum_{l'} NM_{ll'snt} + \sum_{l'} NM_{l'lsnt} \quad \forall l,s,n,t \tag{7}$$

$$NQ_{lsnt} \le nu_{ls} \quad \forall l,s,n,t \tag{8}$$

$$NM_{ll'snt} \le M \times nb_{ll's} \quad \forall l,l',s,n,t \tag{9}$$

- Production and transportation balance constraints

$$XQ_{iljst} = \sum_{l'}\sum_{j'} RQ_{iljsl'j'(s+1)t} \quad \forall i,l,j,s=1,...S-1,t \tag{10}$$

$$\sum_{l'}\sum_{j'} RQ_{il'j'(s-1)ljst} = XQ_{iljst} \quad \forall i,l,j,s=2,...S,t \tag{11}$$

- Capacity constraints

$$\sum_{i}\sum_{j}(XQ_{iljst} \times ks_{ijsk}) \le KQ_{lskt} \times ka_{sk} \quad \forall l,s,k,t \tag{12}$$

$$\sum_{i}\sum_{j}(XQ_{iljst} \times ns_{ijsn}) \le NQ_{lsnt} \times na_{sn} \quad \forall l,s,n,t \tag{13}$$

- Material constraint

$$\sum_{i}\sum_{l}\sum_{j}(XQ_{iljst} \times ms_{ijsm}) \le mq_{smt} \quad \forall s,m,t \tag{14}$$

- Production capability constraint

$$XQ_{iljst} \le M \times tf_{ijs} \quad \forall i,l,j,s,t \tag{15}$$

- Transportation capability constraint

$$RQ_{iljsl'j'(s+1)t} \le M \times tb_{lsl'(s+1)} \quad \forall i,l,j,s,l',j',t \tag{16}$$

- Demand fulfillment constraints

$$\sum_{l}\sum_{j} XQ_{iljst} = SQ_{ict} \quad \forall i,s=S,c,t \tag{17}$$

$$SQ_{ict} \le de_{ict} \quad \forall i,c,t \tag{18}$$

- Service level

$$SL_c = \left[\frac{\sum_i SQ_{ict}}{\sum_i de_{ict}}\right] \quad \forall c,t \tag{19}$$

- Domain restriction for decision variables

$$KQ_{lskt}, KM_{ll'skt}, NQ_{lsnt}, NM_{ll'snt} \in \text{integer} \qquad \forall l,s,k,n,t \tag{20}$$

$$XQ_{iljst}, RQ_{iljsl'j'(s+1)t}, SQ_{ict}, SL_c \ge 0 \quad \forall i,l,l',j,j',s,t,c \tag{21}$$

## III. Sensitivity Analysis

Demand change is the primary problem discussed in this study. The semiconductor packaging and testing industry cannot accurately forecast the actual demand of customers. When the actual demand is lower, capacity waste can be reduced. By contrast, when the actual demand is higher, capacity shortage can be avoided. For the case company in this study, the increasing demand results in continuous improvement in net profit because of the demand growth. Figs. 1 and 2 show the total net profit under the different demand forecasts and parameter levels.

## IV. Conclusion

On the contrary, as demand increases, customer satisfaction rate reaches 100%. Accordingly, in case of limited production capacity, greater demand leads to less satisfaction and low standard of service. Then, the availability of production capacity limitation is assessed. Obviously, a significant difference is observed between the total profit produced in the production capacity without limitations and those produced in the production capacity with limitations. The reason is that in the condition without capacity restrictions, the production flexibility is greater and the customer satisfaction rate also increases. This study finds that changes in production capacity parameters become important factors in satisfying the changes in customer service standards.

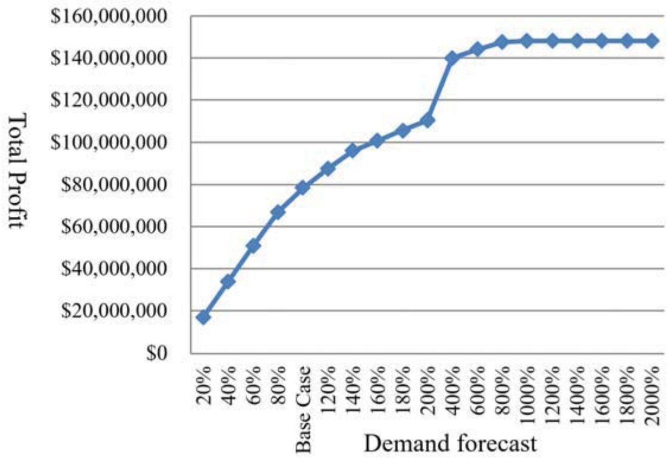


Fig. 1 Total net profit under the different demand forecast

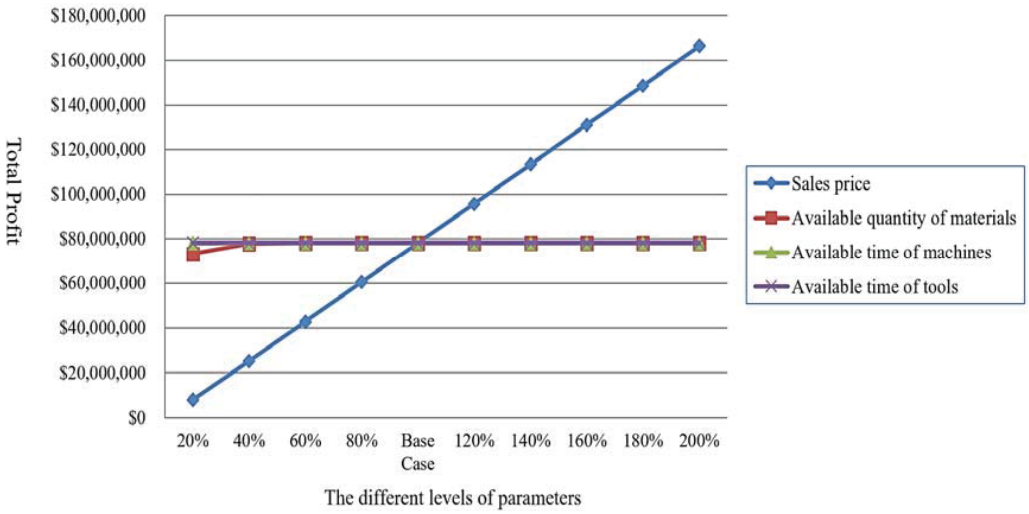


Fig. 2 Total net profit under the different levels of parameters

For the parameter limits of the ability to migrate machines, we compare machines with limited ability to migrate and machines with unlimited ability to migrate. In the latter condition, a greater total profit is gained and the customer demand is 100% satisfied in terms of customer service standards. With regard to the parameter limits of the ability to migrate tools, case studies present results only for those in molding stations so that the tools are limited only in molding stations. A comparison of the limited ability and unlimited ability to migrate the tools shows that in the latter condition, increased total profit is gained, and the customer demand is significantly satisfied in terms of customer service standards. In addition, in investigating the number of migration machines and tools under the conditions of limited or unlimited ability to migrate them, the case study results show that in the latter condition, the machines and tools can be migrated limitlessly to meet increased demand and high customer service standards.

In this study, the influence of price changes, the total available amount of materials, and the available working hours of machines and molds is investigated under various parameter levels. In terms of the parameter levels of price, the changes of parameter levels cause the total profit trend to exhibit a linear relationship and increase in proportion. The total profit is equal to the sales revenue minus production costs, cost of moving machines, and cost of moving tools; thus, the changes in price parameters become an important factor in the changes in total profit. Under the condition of other fixed parameters, we know that in a particular change ratio of the total available amount of materials, the changes in the available working hours of machines and tools can meet the demand capacity and obtain the maximum total profit. If the ratio increases continuously, no significant change in total profit happens, and capacity surplus may even occur. The preceding sections presented the sensitivity analysis and investigation of the case of a large semiconductor assembly and testing company in Taiwan.

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