行政院國家科學委員會專題研究計畫　成果報告

IC 設計公司評選合作封裝廠之模糊層級分析暨隨機產能需求分配模式探討

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IC 設計公司評選合作封裝廠之模糊層級分析暨隨機需求分配模式探討

Fuzzy Hierarchy Analysis to Assess Assembly Factories and Fuzzy Stochastic Outsourcing Capacity Allocation Models for Fabless

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一、中文摘要

關鍵詞：模糊多屬性決策分析方法、模糊隨機規劃、IC 製造業

本研究針對國內 IC 製造業特性，找出影響 IC 設計公司評選 IC 封裝廠商之考量因素及構面，並擬以模糊層級分析法為架構，參酌其他模糊多屬性決策分析方法的優點，發展出一套完整的 IC 設計公司評選合作 IC 封裝廠之輔助決策分析模式，以反映評選小組成員的主觀認知及偏好。此外，本研究並應用可以同時處理兩種不同類型之不確定性資料的模糊隨機規劃理論來建立一個符合國內水平專業分工特性的 IC 封裝產能需求分配模式，以協助落實 IC 設計公司與 IC 封裝廠之代工夥伴合作關係。

二、英文摘要

Keywords: Fuzzy Multi-Criteria Decision Making, Fuzzy Stochastic Programming, IC Manufacturing Industry

This paper aims at developing a decision making tool which can be potentially used by an IC design company to select the appropriate IC assembly factories and to allocate the outsourcing capacity among them. Herein a two-stage decision procedure is indicated to solve the outsourcing capacity allocation problem with uncertainty. In order to select the candidates of IC assembly factories, a fuzzy analytic hierarchy process is presented to generate the cooperation priority in the first stage model. In the second stage model, the outsourcing capacity allocation problem is formulated as a fuzzy stochastic programming model that is to minimize the total fuzzy weighted cost and subject to stochastic demand/supply. Finally, the proposed model is applied to an IC design company in the real world. The results of quantitative analysis and sensitivity analysis prove the superiority of the fuzzy stochastic outsourcing capacity allocation model.

三、計畫緣由與目的

Due to the IC industry’s specific characteristics of the huge investment and rapid depreciation for equipment, the professional division of production is formed to match the need of semi-conductor industry in Taiwan. The Semi-conductor industry in Taiwan currently has developed to a comprehensive supply chain system; its upstream and downstream members can be divided into IC Design, Wafer Manufacture, IC Assembly, IC Testing and Electronic Product Assembly. The division of production is the major difference for the semi-conductor industry between Taiwan and other countries. Therefore, the IC design company in Taiwan is mainly concentrated in product’s design, R&D and marketing; regarding IC manufacturing and testing, they are engaged by the outsourcing OEM factories. How to choose the outsourcing OEM factories and how to allocate the capacity requirements to the chosen outsourcing OEM factories are two essential decisions that impact the profitability and the product quality for the IC design company.

Because the available candidates of wafer factories are limited, choosing the wafer factories isn’t a difficult task for the IC design company. Compared with wafer manufacture, the entry barrier of IC assembly is low. There are 40~50 IC assembly factories in Taiwan. In addition, the diversiform assembly technology is progressively developed. As the assembly technology is complicated, a systematic method is more needed to help the IC design company select IC assembly factories.

Since the IC design company has no production equipment, such a production outsourcing problem totally differs from the traditional production outsourcing planning that is the make-or-buy decision (Venkatesan, 1992; Welch and Nayak, 1992; Company and Ronen, 2000). The production outsourcing problem of an IC design company is how to allocate the capacity requirements among the IC assembly factories. It can be regarded as purchase behaviour in wider explanation. The outsourcing capacity allocation problem is very similar with the purchase distribution for suppliers (Collins and Bechler, 1998). It is well known that several factors affect a supplier's ability. To find appropriate outsourcing OEM factories for the IC design company, it is necessary to make a trade off between tangible and intangible factors. In addition, the capacity and the technology of each IC assembly factory are limited. Generally speaking, no one IC assembly factory can satisfy the total requirements of an IC design company. Hence this is a multi-criteria and multi-sourcing suppler selection problem. As all mentioned above, this study concentrates on exploring the integrated method which is composed of the multi-criteria decision making method and the mathematical programming technique. The goal of the former is to determine the cooperation priority of production outsourcing. According to the resulted cooperation priority, the latter assigns the order quantities among the selected IC assembly factories. This integrated method is particularly described in the next two sections.

四、成果與結論

4.1 Stage One: A Multi-Criteria/ Multi-Sourcing Supplier Evaluation Model

There are many studies about the supplier selection process in the literature. Traditional methodologies of the supplier selection process include the cost-ratio method, the categorical method, weighted-point evaluations, mathematical programming models and statistical or probabilistic approaches (Yan et al. 2003; Oliveria and Lourenço, 2002). Generally speaking, vendors are selected among many suppliers on their ability to meet the quality requirements, the delivery schedule, and the offered price. From the sellers and buyers relationship to the partnership nowadays, the principle for selecting the supplier is getting more and more complicated. The non-quantifiable factors (e.g. technology, process, internal control, human resource, and etc.) are also considered by the enterprises.

For the need of horizontal cooperation of the semi-conductor industry, Su (2001) presents five principles for selecting IC assembly factories, including quality requirements, delivery schedules, internal control, service after sale and enterprise development. Obviously, the quantifiable factors together with the impreciseness of judgement on the intangible evaluation factors are considered by the IC design company. In this study, we adopt the fuzzy analytic hierarchy process (FAHP) approach to deal with the multiple principles and the vagueness of verbally evaluation into the supplier selection model for the IC design company in choosing the IC assembly factories. First, we establish the evaluation principles for the IC design company to select the outsourcing IC assembly factories. Second, we use Buckley's FAHP (1985) to obtain the relative weights and to evaluate the fuzzy indices of each IC assembly factory. Third, we perform the fuzzy sorting method to obtain the cooperation priority of the IC assembly factories.

4.2 Stage Two: A Fuzzy/Stochastic Capacity Allocation Model for Production Outsourcing

Most of the studies are focused on the production planning for the companies in the vertical integration of the semi-conductor industry. The research that explores the outsourcing capacity planning for the companies in the horizontal cooperation of the semi-conductor industry is rather rare. Hsu et al. (2003) present a mechanism of Booking Capacity Planning (BCP) to handle the capacity allocation problem of fabless. The BCP is divided into three stages, net demand planning, net capacity requirement planning, and the outsourcing capacity allocation. The objective is to minimize the total cost including production cost, quality cost, purchase cost, and customer loss cost. However, the proposed outsourcing capacity allocation planning is based on the known production orders. Many uncertain factors from the demand side and the supply side are ignored. In fact, the decision maker of the IC design company indeed faces various uncertainties in the market, including the imprecision of various production costs, the obscurity of yields, the stochasticity of demand, and etc. In order to match the planning condition in reality, the subjective cognizance of decision makers about the future operation condition must be considered when the plan of outsourcing capacity allocation is made. To our knowledge, there is no research explores the outsourcing capacity allocation problem with uncertainties.

As mentioned above, we adopt the fuzzy stochastic programming methodology to establish a general capacity allocation model for IC production outsourcing by means of extending the research of Hsu et al. (2003). First, the relevant production costs vary frequently, because of the fluctuation of material prices. It is quite difficult to predict precisely these costs. Furthermore, the yield rate of each IC assembly factory perhaps changes due to the differences in the assembly process. Besides, the decision maker subjectively recognizes the importance of each production cost according to his/her expertise. Thus we use fuzzy numbers to present these three imprecise data, named fuzzy production costs, fuzzy yield rates, and fuzzy weights. Second, the market demand is changeable before the production orders are received. The IC design company can previously forecast the outsourcing capacity requirements and the available capacity supply of each IC assembly factory, according to the known order quantity as well as the historical data of the capacity requirements and the capacity supply. Thus we assume the capacity requirement and the upper limit of the weekly capacity requirement of the IC design company as well as the upper limit of the capacity supply of the IC assembly factory are estimated as probability distribution.

Notations and definitions

Before the mathematical model is presented, the following notations are defined.

$\tilde{C}_{at}$: The unit production cost of the packaging type t for the IC assembly factory a; it is a fuzzy number

$\breve{D}_{tm}$: The capacity requirement for the packaging type t in the time period m; it is a stochastic variable with the probability distribution function F_{tm}^{D}

$\tilde{L}_{a}$: The customer loss cost per time period that is caused by the IC assembly factory a; it is a fuzzy number

M : A big number

$\tilde{N}_{at}$: The unit quality loss cost of the packaging type t that is caused by the IC assembly factory a; it is a fuzzy number

O_{at} : The upper limit of the weekly capacity for the packaging type t supplied by the IC assembly factory a

$\tilde{P}_{a}$: The purchase cost per time period of the IC assembly factory a; it is a fuzzy number

$\tilde{q}_{a}$: The yield rate of the IC assembly factory a; it is a fuzzy number

$\breve{S}_{atm}$: The upper limit of the capacity of the packaging type t supplied by the IC assembly factory a in the time period m; it is a stochastic variable with the probability distribution function F_{atm}^{S}

$\breve{U}_{tm}$: The upper limit of the weekly capacity requirement of the packaging type t in the time period m, it is a stochastic variable with the probability distribution function F_{tm}^{U}

V_{at} : The lower limit of the promised order quantity for the packaging type t with the IC assembly factory a

$\tilde{W}_{c}$: The fuzzy weight for the production cost

$\tilde{W}_{n}$: The fuzzy weight for the quality loss cost

$\tilde{W}_{l}$: The fuzzy weight for the customer loss cost

$\tilde{W}_{p}$: The fuzzy weight for the purchase cost

$\tilde{\beta}_{D}, \tilde{\beta}_{U}$: The possibility tolerance of the uncertain event; they are fuzzy numbers

β_{S} : The probability tolerance of the uncertain event

All of the above terms define the inputs to the model. The following decision variables are used in the formulation.

X_{atm} : The allocated capacity of the packaging type t for the IC assembly factory a in the time period m

Y_{am} : 1, if the capacity requirement in the time period m is allocated to the IC assembly factory a; 0, otherwise

Y_{atm} : 1, if the capacity requirement for the packaging type t in the time period m is allocated to the IC assembly factory a; 0, otherwise

Model formulation

This model, shown as below, aims to determine an outsourcing capacity allocation plan for the selected IC assembly factories by minimizing the total fuzzy weighted cost.

$$\begin{aligned}\min \quad & \tilde{W}_c \otimes \left[\sum_{a}^{\sim} \sum_{t}^{\sim} \sum_{m}^{\sim} \tilde{C}_{at} \otimes X_{atm} \right] \\ & \oplus \tilde{W}_n \otimes \left[\sum_{a}^{\sim} \sum_{t}^{\sim} \sum_{m}^{\sim} \tilde{N}_{at} \otimes X_{atm} \right] \\ & \oplus \tilde{W}_p \otimes \left[\sum_{a}^{\sim} \sum_{m}^{\sim} \tilde{P}_a \otimes Y_{am} \right] \\ & \oplus \tilde{W}_l \otimes \left[\sum_{a}^{\sim} \sum_{m}^{\sim} \tilde{L}_a \otimes Y_{am} \right]\end{aligned} \tag{1}$$

Subject to

$$\Pr\left(\sum_{a} \tilde{q}_a \otimes X_{atm} \geq \breve{D}_{tm} \right) \geq \tilde{\beta}_D \qquad \forall\ t, m \tag{2}$$

$$\Pr\left(X_{atm} \leq \breve{S}_{atm} \right) \geq \beta_S \qquad \forall a, t, m \tag{3}$$

$$\Pr\left(\sum_{a} \tilde{q}_a \otimes O_{at} \otimes Y_{atm} \geq \breve{U}_{tm} \right) \geq \tilde{\beta}_U \qquad \forall\ t, m \tag{4}$$

$$\sum_{t} \sum_{m} X_{atm} \geq \sum_{t} \sum_{m} X_{(a+1)tm} \qquad \forall\ a = 1, \ldots, A-1 \tag{5}$$

$$\sum_{m} X_{atm} \geq V_{at} \qquad \forall\ a, t \tag{6}$$

$$X_{atm} \leq MY_{atm} \qquad \forall\ a, t, m \tag{7}$$

$$Y_{atm} \leq X_{atm} \qquad \forall\ a, t, m \tag{8}$$

$$\sum_{t} Y_{atm} \leq MY_{am} \qquad \forall\ a, m \tag{9}$$

$$Y_{am} \leq \sum_{t} Y_{atm} \qquad \forall\ a, t, m \tag{10}$$

$$X_{atm} \geq 0 \qquad \forall\ a, t, m \tag{11}$$

$$Y_{am} \in \{0,1\} \qquad \forall\ a, m \tag{12}$$

$$Y_{atm} \in \{0,1\} \qquad \forall\ a, t, m \tag{13}$$

The objective (1) of the model is to minimize the total fuzzy weighted cost that is the weighted sum of the fuzzy production cost, the fuzzy quality loss cost, the fuzzy purchase cost and the fuzzy customer loss cost. For the all individual packaging type and at the all individual time period, Equation (2) requests that the possibility of the total production capacity supplied by all IC assembly factories exceeding an IC design company's capacity requirements must be higher than the possibility tolerance $\tilde{\beta}_D$. Equation (3) restricts that, in each time period *m*, the probability of the allocated capacity of the packaging type *t* not exceeding the capacity limit of the IC assembly factory *a* must exceed the probability tolerance β_S. Equation (4) requests that, in each time period *t* and for each packaging type *t*, the possibility of the total yield of weekly capacity exceeding the limit of weekly capacity requirement is higher than the possibility tolerance $\tilde{\beta}_U$. Equation (5) limits that the IC assembly factory gets the more capacity allocation if it has the dominance of the cooperation priority which is obtained from FAHP. Equation (6) guarantees that the capacity allocation result matches the cooperation requirement. For the specific IC assembly factory *a*, the allocated capacity of packaging type *t* during the cooperation period must exceed the promised quantity. Equation (7) defines the relation between the binary variable Y_{atm} and the real variable X_{atm}. Equation (8) can prevent the unreasonable occurrence, i.e. X_{atm} =0 and Y_{atm} =1. Equation (9) defines the relation between these two 0-1 variables, Y_{atm} and Y_{am}. Equation (10) can avoid the irrational occurrence, i.e. $\sum_{t} Y_{atm}$ =0 and Y_{am} =1. Equation (11) is a nonnegative constraint. Equation (12) and Equation (13) request that Y_{am} and Y_{atm} are binary variables respectively.

Note that we have three kinds of variables in this outsourcing capacity allocation model, i.e. fuzzy, stochastic, and deterministic variables. The dissimilarities between this model and Hsu's model are this model can premeditate the impact of uncertainties and the above outsourcing strategy can be considered in this model. Herein the cooperation priority obtained by the first stage model is regarded as an absolute constraint in the second stage model.

Equivalent deterministic model

We propose a fuzzy stochastic programming model, in which the parameters of the right hand side of constraints are stochastic variables with known probability distribution functions. The coefficients of the objective function and the left hand side of constraints are fuzzy numbers. According to the fuzzy stochastic programming theory proposed by Iskander (2003), the fuzzy stochastic programming model can be transformed into an equivalent deterministic model by using the concept of α-cut and the dominance possibility criterion (Negi and Lee, 1993). Let all fuzzy variables of the proposed model be triangular fuzzy numbers. For clear, they can be denoted as follows: $\tilde{W}_C = \left(\underline{W}_C, W_C^0, \overline{W}_C \right)_{LR}$, $\tilde{W}_N = \left(\underline{W}_N, W_N^0, \overline{W}_N \right)_{LR}$, $\tilde{W}_P = \left(\underline{W}_P, W_P^0, \overline{W}_P \right)_{LR}$, $\tilde{W}_L = \left(\underline{W}_L, W_L^0, \overline{W}_L \right)_{lR}$,

$\tilde{C}_{at} = \left(\underline{C}_{at}, C_{at}^0, \overline{C}_{at}\right)_{LR}$, $\tilde{N}_{at} = \left(\underline{N}_{at}, N_{at}^0, \overline{N}_{at}\right)_{LR}$, $\tilde{P}_a = \left(\underline{P}_a, P_a^0, \overline{P}_a\right)_{LR}$, $\tilde{L}_a = \left(\underline{L}_a, L_a^0, \overline{L}_a\right)_{LR}$, $\tilde{\beta}_D = (\underline{\beta}_D, \beta_D^0, \overline{\beta}_D)_{LR}$, and $\tilde{\beta}_U = (\underline{\beta}_U, \beta_U^0, \overline{\beta}_U)_{LR}$. The transformation result is shown as below:

$$\min \quad Z \tag{14}$$

Subject to

(5)~(13)

$$\min(\underline{Z}_1, \underline{Z}_2) \le Z \le \max(\overline{Z}_1, \overline{Z}_2) \tag{15}$$

$$\begin{aligned}\underline{Z}_1 = & \sum_{atm}\left[\frac{\alpha}{\theta}W_C^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{W}_C\right]\left[\frac{\alpha}{\theta}C_{at}^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{C}_{at}\right]X_{atm} \\ & + \sum_{atm}\left[\frac{\alpha}{\theta}W_N^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{W}_N\right]\left[\frac{\alpha}{\theta}N_{at}^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{N}_{at}\right]X_{atm} \\ & + \sum_{am}\left[\frac{\alpha}{\theta}W_P^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{W}_P\right]\left[\frac{\alpha}{\theta}P_a^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{P}_a\right]Y_{am} \\ & + \sum_{am}\left[\frac{\alpha}{\theta}W_L^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{W}_L\right]\left[\frac{\alpha}{\theta}L_a^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{L}_a\right]Y_{am}\end{aligned} \tag{16}$$

$$\begin{aligned}\underline{Z}_2 = & \sum_{atm}\left[\frac{\alpha}{\theta}W_C^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{W}_C\right]\left[\frac{\alpha}{\theta}C_{at}^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{C}_{at}\right]X_{atm} \\ & + \sum_{atm}\left[\frac{\alpha}{\theta}W_N^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{W}_N\right]\left[\frac{\alpha}{\theta}N_{at}^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{N}_{at}\right]X_{atm} \\ & + \sum_{am}\left[\frac{\alpha}{\theta}W_P^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{W}_P\right]\left[\frac{\alpha}{\theta}P_a^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{P}_a\right]Y_{am} \\ & + \sum_{am}\left[\frac{\alpha}{\theta}W_L^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{W}_L\right]\left[\frac{\alpha}{\theta}L_a^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{L}_a\right]Y_{am}\end{aligned} \tag{17}$$

$$\begin{aligned}\overline{Z}_1 = & \sum_{atm}\left[\frac{\alpha}{\theta}W_C^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{W}_C\right]\left[\frac{\alpha}{\theta}C_{at}^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{C}_{at}\right]X_{atm} \\ & + \sum_{atm}\left[\frac{\alpha}{\theta}W_N^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{W}_N\right]\left[\frac{\alpha}{\theta}N_{at}^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{N}_{at}\right]X_{atm} \\ & + \sum_{am}\left[\frac{\alpha}{\theta}W_P^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{W}_P\right]\left[\frac{\alpha}{\theta}P_a^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{P}_a\right]Y_{am} \\ & + \sum_{am}\left[\frac{\alpha}{\theta}W_L^0 + \left(1-\frac{\alpha}{\theta}\right)\underline{W}_L\right]\left[\frac{\alpha}{\theta}L_a^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{L}_a\right]Y_{am}\end{aligned} \tag{18}$$

$$\begin{aligned}\overline{Z}_2 = & \sum_{atm}\left[\frac{\alpha}{\theta}W_C^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{W}_C\right]\left[\frac{\alpha}{\theta}C_{at}^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{C}_{at}\right]X_{atm} \\ & + \sum_{atm}\left[\frac{\alpha}{\theta}W_N^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{W}_N\right]\left[\frac{\alpha}{\theta}N_{at}^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{N}_{at}\right]X_{atm} \\ & + \sum_{am}\left[\frac{\alpha}{\theta}W_P^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{W}_P\right]\left[\frac{\alpha}{\theta}P_a^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{P}_a\right]Y_{am} \\ & + \sum_{am}\left[\frac{\alpha}{\theta}W_L^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{W}_L\right]\left[\frac{\alpha}{\theta}L_a^0 + \left(1-\frac{\alpha}{\theta}\right)\overline{L}_a\right]Y_{am}\end{aligned} \tag{19}$$

$$\begin{aligned}&\sum_a\left[\alpha q_a^0 + (\theta-\alpha)\overline{q}_a\right] X_{atm} \\ &\quad \ge \alpha F_{D_{tm}}^{-1}\left(1-\beta_D^0\right) + (\theta-\alpha)F_{D_{tm}}^{-1}\left(1-\underline{\beta}_D\right) \quad \forall t,m\end{aligned} \tag{20}$$

$$\sum_a \overline{q}_a X_{atm} \ge F_{D_{tm}}^{-1}\left(1-\underline{\beta}_D\right) \quad \forall t,m \tag{21}$$

$$\begin{aligned}&\sum_a\left[\alpha q_a^0 + (\theta-\alpha)\overline{q}_a O_{at} Y_{atm}\right] \\ &\ge \alpha F_{U_{tm}}^{-1}\left(1-\beta_U^0\right) + (\theta-\alpha)F_{U_{tm}}^{-1}\left(1-\underline{\beta}_U\right) \quad \forall t,m\end{aligned} \tag{22}$$

$$\sum_a \overline{q}_a O_{at} Y_{atm} \ge F_{U_{tm}}^{-1}\left(\underline{\beta}_U\right) \quad \forall t,m \tag{23}$$

$$X_{atm} \le F_{atm}^{S\ -1}\left(\beta_S\right) \qquad \forall\ a,t,m \tag{24}$$

Where θ represents the maximum value of membership functions, $0 < \theta \le 1$; α represents the α-cut of fuzzy numbers, $0 < \alpha \le \theta$. Every decision maker can carry out setting by the personal subjective knowledge and the point of view, $0 < \alpha \le \theta \le 1$.

4.3 Real Case Study

This multi-criteria/multi-sourcing capacity allocation method is applied to a professional IC design company, Company T, which is located in Hsinchu Science Park. This company was established in October 1997, which engaged in the personal computer peripherals, mobile communication, consumption electronics, etc. This IC design company has very close cooperative relationships with couples of outsourcing OEM factories. There are five IC assembly factories, which have been the outsourcing factories of Company T and represented by the code from A to E respectively.

Results of the first stage model

By means of having interviews with the specialist and technician, the evaluation structure of selecting the outsourcing assembly factories for the IC design company is established, as shown in Table 1. The principle includes the production technology and product quality, flexibility, price, financial conditions and business reputation, internal control, as well as service. There are two to five sub-principles under each main principle. Furthermore, ten technicians of Company T express their fuzzy pairwise comparison judgments about the preference between evaluation principles. All values of the consistency index for each fuzzy pairwise comparison are less than or equal to the tolerance value, 0.1. The resulted fuzzy weights are listed in Table 1. Then, each technician in the assessment team is asked to express linguistically the degree of satisfaction with the subprinciples of each IC assembly factory. Herein five fuzzy linguistic variables are used to describe the degree of satisfaction, that is, "Excellent", "Good", "Satisfactory", "Unsatisfactory", and "Poor". The corresponding triangular fuzzy numbers are assumed as (0.7,0.9,1.0)*, (0.5,0.7,0.9), (0.3,0.5,0.7), (0.1,0.3,0.5), and (0.0,0.1,0.3). Five fuzzy relation matrices are constructed by using geometric mean method to synthesize the ten persons' opinions. Finally, we have the fuzzy synthetic index for each IC assembly factory by performing fuzzy synthetic analysis. These five fuzzy synthetic indices are ranked by the fuzzy sorting. Thus the cooperation priority is established as follow:

Factory A is better than Factory B, after that Factory E follows, then Factory C goes next, and Factory D is the worst.

Note that this result shows the consistency with the actual outsourcing arrangement of Company T. IC assembly factory A is the major contractor that Company T has ever outsourced. The IC assembly factory D only has few orders. Other IC assembly factories, B, C, and E, are the backup candidates to cover the capacity shortage of IC assembly factory A. This phenomenon proves the practicability of the proposed FAHP model.

Results of the second stage model

Quad Flat Package (QFP), Dual In-line Package (DIP), Small Outline Package (SOP) are the major package types for producing the major products of Company T. The stochastic capacity requirement of each packaging type is predicated according to the historical customers' orders, including the monthly capacity requirement and the upper limit of the weekly capacity requirement between April 2003 and September 2003. All of them follow the uniform distributions, as summarized in Table 2. Furthermore, only the top three IC assembly factories, i.e. Factory A, Factory B, and Factory E, are taken to carry out the outsourcing capacity allocation without losing generality. All of the fuzzy input data of IC assembly factories are listed in Table 3. For each IC assembly factory, the stochastic limits of capacity supply of each packaging type are listed in Table 4. We also assume these stochastic parameters follow the uniform distributions.

Next, the fuzzy weight of each term of the objective function is determined by applying again FAHP. The resulted fuzzy weights of the production cost, the quality loss cost, the purchase cost, and the customer loss cost are (0.277,0.277,0.324), (0.05,0.061,0.087), (0.053,0.064,0.095), and (0.545, 0.598, 0.939) respectively. In addition, the possibility tolerance and the probability tolerance are set as $\tilde{\beta}_D = \tilde{\beta}_U = (0.85, 0.9, 0.95)$ and β_S =0.9 respectively. By using the above data and applying mathematical programming software LINGO, the proposed fuzzy stochastic capacity allocation model is solved. For purposes of demonstration, we set the value of α-cut and the maximum value θ of each membership function as 0.8. The yielded capacity allocation result is shown in Table 5. The total cost is NT$1062408.

The actual allocation of the outsourcing capacity requirements of Company T among the three IC assembly factories is shown in the top part of Table 6. The total cost is NT$1127749. While the possibility tolerance is set as $\tilde{\beta}_D = \tilde{\beta}_U = (1.0, 1.0, 1.0)$ and the probability tolerance is set as β_S =1.0, it means that the decision maker cannot accept any uncertainty existed in the planning result. Under such a condition, the proposed fuzzy stochastic capacity allocation model becomes the deterministic capacity allocation model. The yielded capacity allocation result is shown in Table 7. The total cost is NT$1108506. After comparison, we found that no matter in the deterministic programming model or in the fuzzy stochastic programming model, the total cost is lower than the actual outsourcing capacity plan of Company T. The total cost of the fuzzy stochastic programming model is the lowest in the three situations. Therefore we can prove that it indeed reduces the total cost by adopting the proposed fuzzy stochastic programming model to allocate the outsourcing capacity requirements. Note that the actual arrangement of the capacity allocation

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* (*a*,*m*,*b*): The numbers in the bracket denote the parameters of triangular fuzzy number. *a* is its least possible value. *b* is its main value. *c* is its highest possible value.

doesn't meet the requirement of the cooperation priority. It may cause the increment of the total cost.

4.4 Conclusions and Suggestions

As the competition in the semi-conductor industry is getting keen day by day, only the division of production is insufficient for sustaining the professional superiority for competition in the Taiwan semi-conductor industry nowadays. The IC design company has to adopt other competition strategies in order to overcome the difficulties from the market uncertainties. Progressing partnership with the OEM factories is one of the useful strategies. That is, the cooperation levels between IC design company and all the OEM factories must be upgraded. Having the technical assistance provided by the proposed two-stage model, the total cost of the production outsourcing can be further reduced. According to the above results, some conclusions are as follows: First, the proposed FAHP model can help the IC design company determine the cooperation priority of the IC assembly factories by means of simultaneously considering multiple criteria. Next, we propose the fuzzy stochastic outsourcing capacity allocation model, which is a powerful analysis tool to actually implement the partnership strategy. In this paper, we follow this principle to allocate outsourcing production capacity, i.e. the higher-priority IC assembly factory must be allocated more outsourcing capacity than the lower-priority IC assembly factory. Under the constraints of the stochastic demand/supply, the fuzzy total cost is minimized to determine the capacity allocation plan.

We believe such a successful way of progressing partnership can be adopted by the IC design companies in the semiconductor industry of other countries. Although only the issue of the outsourcing capacity allocation for the assembly production is explored in this study, this integrated two-stage decision method can be extended to tackle the outsourcing capacity allocation problem for each production stage for the IC design company. Furthermore, other implements of progressing partnership would be considered in the future study, e.g. quantity flexibility, backup agreements, buy back or return policies, incentive mechanisms, revenue sharing, quantity discounts, etc.

五、計畫成果自評

在一年的研究期間，我們完成模式建與演算法機制發展工作，並完成實證分析。研究成果已經發表於國際重要研討會 **The 36th International Conference on Computers and Industrial Engineering**。

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Table 1: The Evaluation Principle Structure and Fuzzy Weights for an IC Design Company Selecting the Outsourcing Assembly Manufactories

principle	fuzzy weight: least possible value	fuzzy weight: main value	fuzzy weight: highest possible value	sub-principle	fuzzy weight: least possible value	fuzzy weight: main value	fuzzy weight: highest possible value
production technology and product quality	0.142	0.249	0.269	capability for persistent improvement	0.0138	0.0383	0.0646
				yield rate	0.0459	0.0896	0.0968
				capability of upgrading technology in accordance with future plan	0.0138	0.0381	0.0554
				equipment and testing software	0.0138	0.0242	0.0516
				production capacity	0.0214	0.0588	0.0656
flexibility	0.11	0.248	0.269	accuracy of delivery schedule	0.0541	0.2073	0.2249
				flexibility for dealing with changed order	0.0180	0.0407	0.0751
financial condition and reputation	0.071	0.071	0.192	business reputation	0.0260	0.0373	0.1010
				debt-to-asset ratio	0.0125	0.0135	0.0445
				onetime performance	0.0202	0.0202	0.1229
price	0.188	0.269	0.269	offered price	0.0681	0.1716	0.1716
				capability for markdown	0.0681	0.0974	0.1716
internal control	0.071	0.088	0.153	management of warehouse equipment	0.0128	0.0181	0.0444
				education training of employees	0.0117	0.0146	0.0286
				operation condition of 5S	0.0144	0.0179	0.035
				executive ability of examining and testing in process	0.0110	0.0182	0.0317
				related operation process and executive ability for dealing with changed process	0.0135	0.0192	0.0438
service	0.062	0.075	0.093	treatment for customer complaining	0.0292	0.0617	0.0764
				capability for sharing information	0.0110	0.0133	0.0289

Table 2: The Range of Predicated Capacity Requirement

monthly capacity requirement (dice/month)						
packaging type	time period: 1	2	3	4	5	6
QFP	[17682,19544]	[20208,22336]	[25261,27920]	[27788,30713]	[18948,20942]	[16416,18144]
DIP	[17290,19110]	[19855,21945]	[24795,27405]	[27265,30135]	[18592,20549]	[16112,17808]
SOP	[16872,18648]	[18525,20475]	[23180,25620]	[16388,18113]	[12635,13965]	[10783,11918]
upper limit of weekly capacity requirement (dice/week)						
packaging type	time period: 1	2	3	4	5	6
QFP	[6631,7329]	[7578,8376]	[9472,10470]	[10421,11517]	[7105,7853]	[6156,6804]
DIP	[6484,7166]	[7446,8230]	[9299,10277]	[10225,11301]	[6972,7706]	[6042,6678]
SOP	[6372,6993]	[6947,7679]	[8693,9608]	[6146,6792]	[4739,5237]	[4043,4469]

Table 3: The Fuzzy Input Data of the IC Assembly Factories

	factory	packaging type: QFP	DIP	SOP
unit production cost (NTD/dice)	A	(2.9,4.8,6.7)*	(0.92,1.5,2.1)	(0.86,1.4,1.95)
	B	(2.8,4.6,6.4)	(0.98,1.6,2.2)	(0.79,1.3,1.79)
	E	(3,4.7,8)	(1.02,1.6,2.8)	(0.89,1.4,2.45)
unit quality loss cost (NTD/dice)	factory	QFP	DIP	SOP
	A	(0,0.027,0.054)	(0,0.019,0.037)	(0,0.02,0.04)
	B	(0,0.083,0.139)	(0,0.058,0.097)	(0,0.062,0.103)
	E	(0.027,0.109,0.19)	(0.02,0.079,0.139)	(0.02,0.08,0.14)

Table 3(continued 1): The Fuzzy Input Data of the IC Assembly Factories

	factory	QFP	DIP	SOP
unit purchase cost (NTD/order)	A	(4560,4800,5040))*	(4560,4800,5040)	(4560,4800,5040)
	B	(4975,5236,5497)	(4975,5236,5497)	(4975,5236,5497)
	E	(5177,5450,5723)	(5177,5450,5723)	(5177,5450,5723)
unit customer loss cost (NTD/order)	factory	QFP	DIP	SOP
	A	(1187,1720,2253)	(1187,1720,2253)	(1187,1720,2253)
	B	(962,1374,1786)	(962,1374,1786)	(962,1374,1786)
	E	(1200,2068,2895)	(1200,2068,2895)	(1200,2068,2895)
yield rate	factory	QFP	DIP	SOP
	A	(0.98,0.99,1)	(0.98,0.99,1)	(0.98,0.99,1)
	B	(0.95,0.97,1)	(0.95,0.97,1)	(0.95,0.97,1)
	E	(0.93,0.96,099)	(0.93,0.96,099)	(0.93,0.96,099)

* (a,m,b) denotes a triangular fuzzy number.

Table 4: The Range of Stochastic Capacity Supply

factory	QFP	DIP	SOP
A	[12000,20000]*	[13000,21000]	[10000,18000]
B	[10000,15000]	[13000,18000]	[8000,13000]
E	[10000,14000]	[80000,12000]	[10000,14000]

* unit: dice/month

Table 5: The Outsourcing Capacity Allocation Result of the Fuzzy Stochastic Programming Model

factory	packaging type	time period 1	2	3	4	5	6	subtotal
A	QFP	7578*	10419	12800	12800	8862	6293	58752
	DIP	12332	11942	3625	13169	13800	13800	68668
	SOP	8731	8637	10800	9853	4431	2550	45002
B	QFP	10500	0	10500	10500	10500	10500	52500
	DIP	5283	0	13500	13500	5133	2585	40001
	SOP	8500	0	8500	6700	8500	8500	40700
E	QFP	0	10325	2526	5151	0	0	18002
	DIP	0	8400	8400	1200	0	0	18000
	SOP	0	10400	4433	168	0	0	15001
total capacity					356626			

*unit: dice/month

Table 6: The Actual Arrangement of the Outsourcing Capacity Allocation

factory	packaging type	time period 1	2	3	4	5	6	subtotal
A	QFP	4000*	6000	11000	11000	10600	8000	50600
	DIP	13000	13000	13000	13000	13000	13000	78000
	SOP	9500	8200	9200	8100	6000	4000	45000
B	QFP	10000	10000	10000	10000	10000	10000	60000
	DIP	4800	3600	7000	11800	7800	5000	40000
	SOP	8000	8000	8000	8000	8000	8000	48000
E	QFP	5300	6000	6500	9200	0	0	27000
	DIP	1000	5000	7000	5000	0	0	18000
	SOP	1000	4000	8000	2000	0	0	15000
total capacity					381600			

*unit: dice/month

Table 7: The Outsourcing Capacity Allocation Results of the Deterministic Programming Model

factory	packaging type	time period						subtotal
		1	2	3	4	5	6	
A	QFP	12000*	11689	12000	12000	10349	7657	65695
	DIP	12566	13000	13000	13000	13000	10536	75102
	SOP	10000	10000	10000	9586	5596	3627	48809
B	QFP	0	10000	10000	10000	10000	10000	50000
	DIP	0	361	13000	13000	6907	6732	40000
	SOP	0	8000	8000	8000	8000	8000	40000
E	QFP	7014	0	5219	7990	0	0	20223
	DIP	6000	8000	646	3355	0	0	18001
	SOP	8188	1917	7021	0	0	0	17126
total capacity		374956						

*unit: dice/month