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# Capacity Collaboration in Semiconductor Supply Chain with Failure Risk and Long-term Profit

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## 1. Introduction

A large proportion of the product mix of the semiconductor manufacturer is of relatively short life cycle (one or two years, typically), and a semiconductor chip may lose 60 percent of value within the first half year of its life cycle (Mallik, 2007). The increasingly challengeable environment of a semiconductor can be characterized by randomly periodic demand, high manufacturing lead time, the expensive set-up costs, and the rapid change of technology, all of which mean significant capital and big risk. The effective capacity scheme of the semiconductor supply chain is of one major measure in order for less capital waste and lower failure risk.

Silicon is the initial and most critical raw material of the semiconductor industry. Today, most semiconductor chips and transistors are created with silicon. The first step in the production of semiconductor silicon device is the drawing of ingots of silicon. These ingots are sliced into wafers. After several layers of semiconductor material are placed on the wafers, they are cut into individual chips. Depending on the complexity of the circuits involved, each wafer may yield between 10 and 100,000 chips. The individual chips can then be measured against one or more dimensions of electrical performance and classified as different products. Then, the final products are finished after dozens of manufacturing processes. A more detailed description of the production process can be found in several references (Kothari, 1984; Bitran & Tirupati, 1988).

Capacity management and planning is always central to the competitiveness of a semiconductor manufacturer. Unlike other high capital requirement industries, the semiconductor industry is competing in the environment of short product life cycles, near-continuous technological innovation and the changing customer demands. A semiconductor supply chain must produce a variety of products in a number of different production facilities as they endeavour to meet the requirements of the customers and capture market share. Because the low flexibility of the equipments, one critical puzzle turns up: how should the existing capacity be configured in order to meet customer demand? This problem

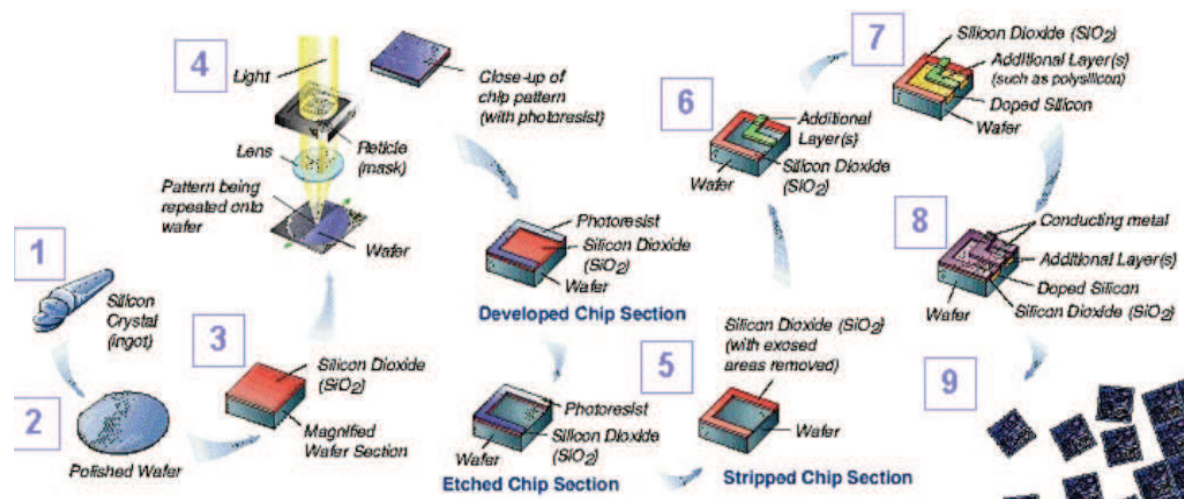


Fig. 1. Semiconductor manufacturing processes (SEMATECH Inc.<sup>1</sup>)

of capacity planning becomes especially challenging during the recent economic crisis. However, effective capacity management tools are not applied in semiconductor industry, many intensive investments have been done by an Indian research institute (see figure 2).

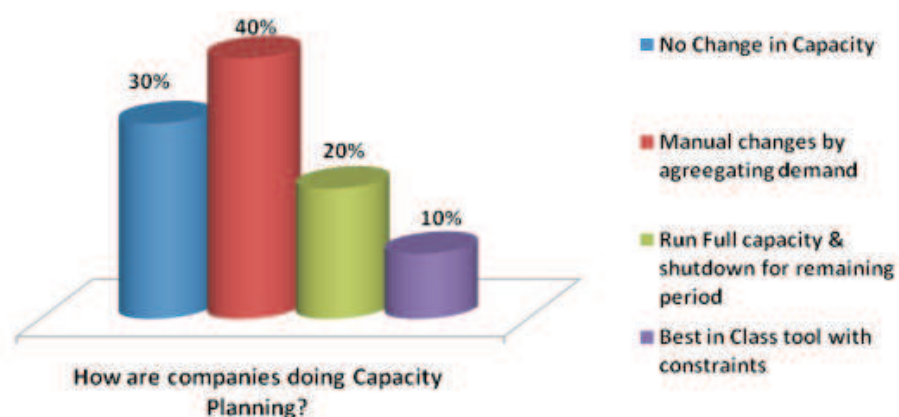


Fig. 2. Capacity management in semiconductor firms (Tata consultancy<sup>2</sup>)

According to their researches, most of the semiconductor manufacturers have best-of-breed advance planning systems to aggregate an optimized plan for capacity management. 40 percent respondents agreed to incorporation of manual overrides in capacity planning. Now, capacity model in capacity planning solution has been relaxed to adapt the current downturn depending on the solution used and the capability of the solution to model manufacturers' capacity.

This paper considers a simple and typical semiconductor integrated manufacturing and allocating system, which consists of one silicon material supplier, multiple manufacture manufacturers and multi-demand (see figure 1). The raw material (silicon) supplier offer silicon to the manufacturers, then several classes of products are made. We attempt to

<sup>1</sup> SEMATECH settled at Texas, traces its history back to 1986, she focuses on improving the industry infrastructure, particularly by working with domestic equipment suppliers to improve their capabilities.  
<sup>2</sup> Tata Consultancy Services (TCS) (BSE: 532540) is a Software services consulting company headquartered in Mumbai, India. TCS is the largest provider of information technology and business process outsourcing services in Asia.

determine the optimal quantity of the material input of the material supplier and the capacity of each manufacturer.

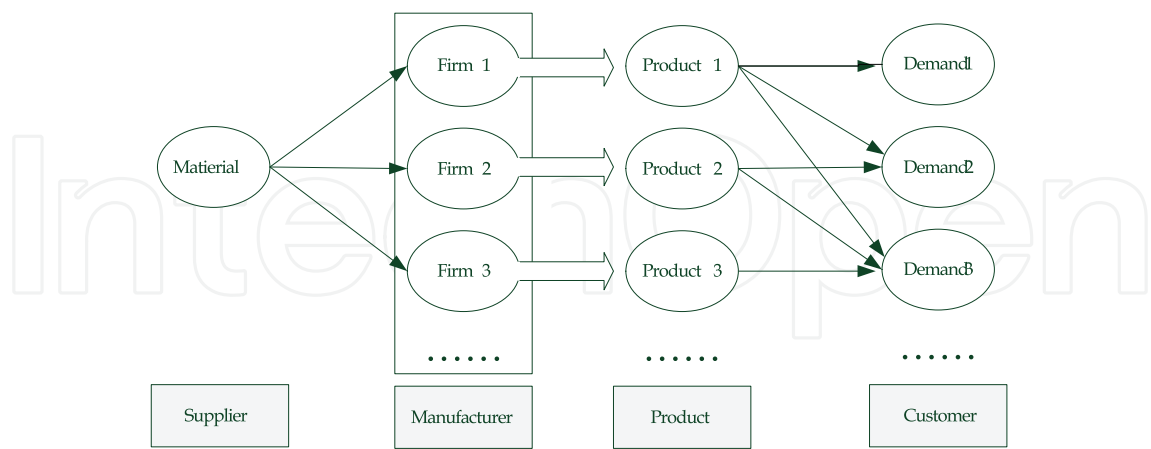


Fig. 3. The semiconductor supply chain

The contributions of this paper are threefold. First, it extends the previous research to a multi-products, random demands semiconductor manufacture and allocation system with downward substitution. Second, we settle an integrated model of the capacity decision problem, and find its several characters. Third, an effective method is designed to solve the proposed stochastic programming model.

The rest of the paper is organized as follows. Section 2 gives an exhaustive literature review, summarizes the exiting researches in the field. Section 3 describes the basic model, which is a stochastic programming model. In section 4, we prove several characters of the model and show that the single-step substitution policy is not necessarily be the optimal rule for allocating products among different demand classes. In section 5, an effective solution method is designed to solve the proposed programming model. Section 6 concludes the paper.

2. Literature review

Some literatures have focused on capacity coordination problem of a manufacture and distribution integrated system with the view of information asymmetry or symmetry, for example, designing an incentive mechanism by a manufacturer to encourage all retailers provide their private information to the manufacturer (Cachon & Lariviere, 1999). The decision of capacity allocation is based on supply and demand in the market, however, the information from production department and marketing department may be opposite, that is the production department aims to meet the demand of orders while the sales manager aims to carry out the sales targets. Then, some researchers study the incentive mechanism for the production department and the marketing department by information screening method to make the optimal decision of capacity allocation (Mallik, 2007). Meanwhile, capacity allocation problem of two-echelon supply chain under information symmetry is studied by some researchers. For example, a few references present a similar problem of capacity allocation decision with the change rate of the linear price under the capacity reservation contract (Erkoc & Wu, 2005), or make the capacity reservation contract according to the changing demands to maximize the total profit (Brown & Lee, 1998). In addition to the literatures above, some researchers have focused on the capacity coordination problem with the perspective of supply chain structure. By means of the

theoretical analysis and model deduction, some references discuss the benefits of supply chain capacity coordination and give some suggestions on the management (Corbett & Rajaram 2006). There are also some literatures study the issue of semiconductor wafer manufacturer's capacity allocation decision problems and establish the network flow model of capacity allocation through a heuristic algorithm (oktay & Uzsoy, 1998). Then, other researches extend a mathematical model to compute the number of retailers for the supply chain profit maximization and several examples prove the validity of the model (Netessine & Rudi, 2003). However, their objective is only to maximize the profit of manufacturer, the supply chain profit may not be optimal. In order to optimize the supply chain performance, a few literatures study a specific capacity allocation problem with the deterministic supply chain capacity (Rupp & Ristic, 2000), and then analysis capacity coordination problems among semiconductor wafer plants under the deterministic capacity with discrete event simulation approach (Gan et al., 2007). They show that the capacity coordination among plants can reduce the supply chain response time. Thus, the CRPS system (Capacity Requirements Planning System) is established towards the problem to decrease the computation burden (Chen et al., 2008). Generally, mathematical programming method is one of normal methods in settling the capacity coordination problems (Wu et al., 2009). A comparative study on semiconductor plants capacity coordination models shows that the capacity coordination among plants on the same supply chain stage can increase total production capacity ability for more than 3% (Chen & Chien, 2010).

In general, most of the researches consider the supply chain coordination mechanisms (e.g. contract mechanism) and their decision variables are mostly the supply chain output rather than capacity. Some other literatures focus on the capacity allocation problem of a manufacturer and the corresponding solving methods always be the situational theory and intelligent algorithms. Most of researches about capacity coordination problem of the supply chain recently mainly focus on the parallel coordination issues, and the common solving method is mathematical reasoning and intelligent simulation approach (Chien & Hsu, 2006; Chien et al., 2007). In this work, we study the coordination of the whole semiconductor supply chain.

Actually, substitution problems with random demand are common in the semiconductor industries. Because the nature performance of a product is highly sensitive to the production equipment and the manufacturing line is less of flexibility, the nature performance of the products made by different manufacturers is probably different. The products can be classified and indexed by the metrical performance, and then be allocated to the corresponding demands. The demands for one certain type of product can be upgraded when its corresponding product has been depleted. The manufacture processes are very complex and the nature performance is sensitive to the production conditions, so the products that are original planed to supply to the customer may be failed. The monopolistic material supplier controls the critical material of silicon, so she can control the yield of each manufacturer, in other words, she is able to control the supply of whole supply chain network.

### 3. Modelling

#### 3.1 System dynamics simulations

Many management efforts are to enhance the specific manufacturing processes through statistical and experimental analysis, but they fail to manage the yields of overall manufacturing processes. Some researches on yield management mainly based on the price-



setting problem, because the price policies always carried out in conjunction with other options such as inventory control (Curry, 1990; Wollmer, 1992; Brumelle, 1990; Robinson, 1994), revenue management (Bassok & Ernst1, 1995; Feng & Xiao, 2000; Bitran & Gilbert, 1996), and so on. A few papers discuss the system approaches to solve manufacturing problems(Doniavi, Mileham & Newnes, 1996) and to determine the effects (Sack, 1998).They analysis the workflow of the manufacturers(see figure 4) and involve a series of models on the integrated system and the discrete subsystems, then solve the problem step by step by mathematical method. As for the semiconductor manufacturing industry, yield is usually considered as one of the most important performance indices (Horton, 1998). A few researches use system simulation method to solve yield problems in integrated manufacturing systems, but a simple and effective methodology is still under development.

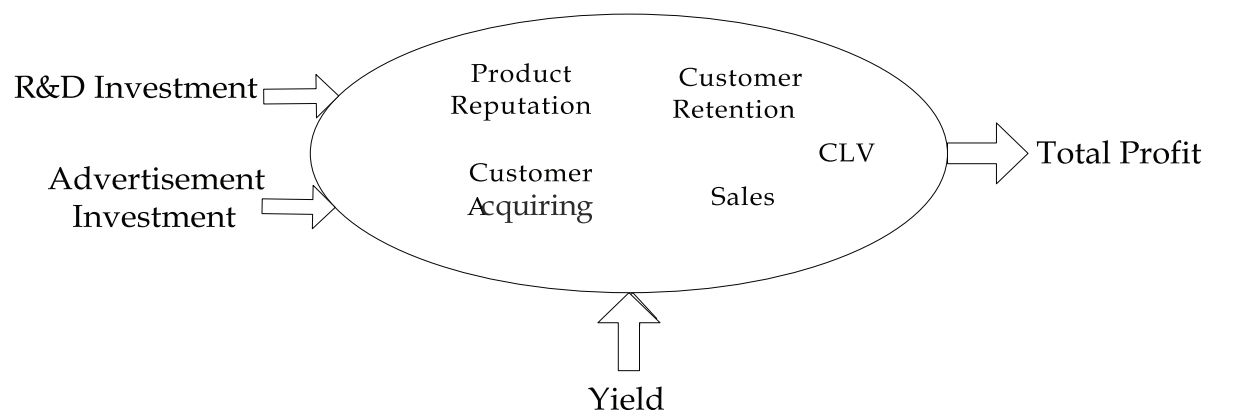


Fig. 4. The capacity decision network of a manufacturer

3.2 Forecasting model

The main sources of uncertainty include demand forecast and capacity estimation, among others. Many manufacturers use the forecasting tools to do capacity plans. An America semiconductor manufacturer once made a five-year capacity decisions only basing on the results from forecasting tools, they find that there is a great gap between the forecast data and the realized data (Christie & Wu, 2002)(see table 1.and table 2.).

Technology code	Demand				
	Year				
	1	2	3	4	5
1	-	-	114	845	1310
2	-	-	51	792	1353
3	156	1348	2001	1616	1307
4	-	165	1550	1668	1366
5	849	747	485	417	395
6	359	572	6457	359	443
7	2708	1982	1092	763	614
8	684	669	433	290	250
9	175	120	75	56	19

Table 1. Capacity forecast

Technology code	Gap between capacity forecast and the realized results				
	Year				
	1	2	3	4	5
1	-	-	84	159	535
2	-	-	51	731	670
3	57	235	276	55	622
4	-	76	227	248	134
5	69	100	196	355	395
6	27	85	101	6	46
7	659	570	743	1072	1221
8	14	61	295	438	479
9	150	174	194	213	251

Table 2. The gap between capacity forecast and the realized results

3.3 Mathematical modeling

We assume that the total material quantity which the silicon supplier determined to input is  $Q$ , and the production output quantities of manufacturers are proportional to the input quantity. The production system has a fixed yield coefficient for each of the products, which we collectively denote by  $e_1, e_2, \dots, e_n$ . If  $Q_i$  is the material input quantity for manufacturer  $i$ , then the production output quantity is  $e_i Q_i$ . We consider a downward substitution structure of the products that classes are numbered so that the class with superior quality is numbered 1 and the class with inferior quality is numbered  $n$ , so that product  $i$  can substitute for product  $j$  if  $i \leq j$ . The demand for each class maybe random, but we assume that the probability distributions of the demands are known. To demonstrate the problem clearly and intently, we give a strict assumption that each demand comes from only one customer. We consider the following costs: production cost, usage cost, shortage cost and expected failure cost, meanwhile, we also consider the following revenues: selling price, the customer lifetime value that result from the satisfied demand. All costs and revenues are assumed to be proportional with their respective quantities. We use the following notation in the paper.

$i, j$	The product and demand class index
$p_i$	Price that the customer will offer towards demand $j$ per unit.
$v_i$	Penalty cost of demand $j$ if unsatisfied.
$u_i$	Usage cost of product $i$ per unit.
$d_i$	Demand quantity for product $j$ .
$Q_i$	Material quantity supplied to manufacturer $i$ .
$Q$	Total material supplied to the system.
$e_i$	Yield coefficient of product $i$ .
$U_j$	Customer life time value of customer $j$ .
$I_i$	Residual quantity of product $i$ before manufacturing rotation.
$C$	Total cost of product $i$ before finished, including manufacturing and material expenses.
$k_i^t$	The probability of the customer $i$ is belongs to type $t$ .
$y_{i,j}$	The quantity of products $i$ that are used to satisfy demand $j$ .

$f_{i,j}$	The failure risk that use product $i$ to satisfy demand $j$ .
$\alpha_{i,j}$	Contribution margin for satisfying a demand of class $j$ with product $i$ .
$t$	The customer type, $t=1,2,\text{or}3$ .
$f_j^t(r_j)$	Customer lifetime value of customer $j$ type $t$ .
$r_j$	The quantity of the realized demand class $j$ .
$h_i$	The holding cost of product $i$ per unit.
$\Pi(Q)$	The total profit of the integrated supply chain.
$a_1, b_1, a, b, a_2, b_2$	The constants in CLV function

### 3.3.1 The customer lifetime value

In marketing, customer lifetime value (CLV) is the present value of the future cash flows attributed to the customer relationship. Use of customer lifetime value as a marketing metric tends to place greater emphasis on long-term customer satisfaction, rather than on maximizing short-term sales. CLV is directly influenced by customer satisfaction, which is positively related to the fulfil rate of the demand. The customer satisfaction is an inside feeling, so it may be different among individuals. We assume that  $U_j=f_j(r_j)$  based on utility curves theory (Becker et al. 1964), where  $r_j$  denotes fulfil rate of demand  $j$ . The CLV curve is depicted in the following figure.

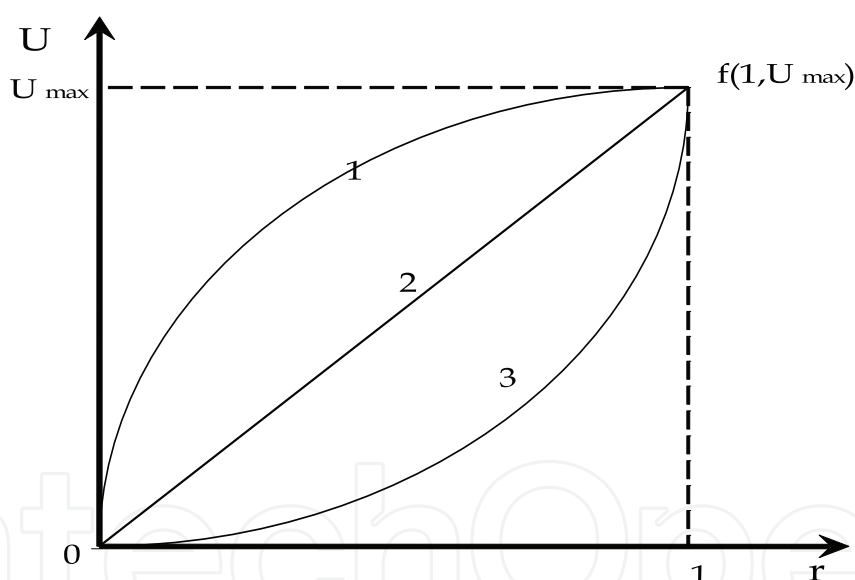


Fig. 5. Relationship between demand fulfil rate and CLV value

In figure 5, curve 1 denotes the CLV of positive customer, curve 2 denotes the CLV of neutral customer and curve 3 denotes the CLV of conservative customer. It is obviously that the CLV values are identical among all types of customers when their demands are fulfilled. The probability of the customer  $j$  is belongs to type  $t$  is  $k_j^t$  ( $t=1,2,3$ ), so  $\sum k_j^t = 1$ . We assume the CLV functions  $f_j^1(r_j), f_j^2(r_j), f_j^3(r_j)$  along with customer types based on the utility curves theory (Becker et al. 1964). The functions equal to  $a_1 - b_1 e^{r_j}, a + b r_j, a_2 + b_2 e^{r_j}$ , respectively, and the parameters  $a, b, a_1, b_1, a_2, b_2$  are constants. The functions have the following relationships:  $f_j^1(1) = f_j^2(1) = f_j^3(1) = 0$  and  $f_j^1(1) = f_j^2(1) = f_j^3(1) = U_{max}$ . If  $0 < r_j < 1$ , we have  $f_j^1(r_j) > f_j^2(r_j) > f_j^3(r_j)$ .



$$f_j(r_j) = \begin{cases} a_1 - b_1 e^{r_j} & (\text{neutral customer}, t = 1) \\ a + b r_j & (\text{positive customer}, t = 2) \\ a_2 + b_2 e^{r_j} & (\text{conservative customer}, t = 3) \end{cases}$$

### 3.3.2 The failure risk cost

System failure risk is often happened in the semiconductor supply chains, and they always result to great capital losses. Failure risks of the stochastic manufacture system mainly come from the equipment failure, the shipping failure in transport, or the high technology demands. In the system, there is always a probability that each piece of ordered product will not be supplied to the customer. In this chapter, we use  $f_{ij}$  to describe the probability of the failure of one unit of product shipment: use product  $i$  to satisfy the demand class  $j$ . If we planed to use product  $i$  to satisfy the demand  $j$  for  $q$  piece, the expect failure cost of the supplement is  $qf_{ij}$ .

### 3.3.3 Other costs and revenues

In the manufacture and allocation system, the material supplier must buy the materials from the outside of the system. Then, the manufacturing process starts, the manufacturers spent the consumables to conduct manufactures. If the products are not fully sold, it will be hold in stock and allocate in the next selling period. The fulfilled demand will increase the customer life time value, because the fulfilled customer may suggest others to purchase or will maintain the bought products. When the demands are not fulfilled, the retailer should pay the shortage cost to the customers. So, on the view of the integrated system, the other costs are the material cost, holding cost, shortage cost. At the same time, the system gains the revenue from products' selling.

### 3.3.4 Model constraints

The system faces some constraints. For example, the demand constraint: the supplied quantity to a certain demand should not exceed the need, that is,  $\sum y_{i,j} \leq d_i$ . At the same time, all the realized demand fulfilled by the one type of product should not exceed the total quantity in inventory, that is,  $\sum_i y_{i,j} \leq e_i Q_i + I_i$ .

### 3.3.5 Model construction

Generally, higher classes of products have higher revenue and usage costs, so it is reasonable that the revenue ( $p_j + v_j$ ) and usage cost  $u_j$  decrease with the index  $j$ . Then we have:

$$p_j + v_j > p_i + v_i, \quad u_j > u_i \quad \text{for } j < i \quad (1)$$

$$\alpha_{i,j} = p_j + v_j - u_i + U_j / \sum_i y_{i,j}, \quad (2)$$

Let  $\Pi(Q)$  be the profit function of the supply chain in the whole manufacturing and selling rotation. In the production stage the supplier determines the optimal material quantity that will be input in the manufacturing system, then, varieties products are manufactured and

shipped to the customers under a proper allocation policy. Our objective is to determine the optimal material quantity and the capacity of each manufacturer in order to maximize the profit function. We formulate this problem as a programming model, and it is as follows:

$$\Pi(Q) = \max_{d_1, \dots, d_n, k_j^t} [(\sum_{i,j} \alpha_{i,j} y_{i,j} - \sum_i v_i d_i) + \sum_j U_j - CQ - f_{i,j} y_{i,j} - h_i(e_i Q_i + I_i - \sum_j y_{i,j})] \quad (3)$$

Where,

$$U_j = k_j^t f_j(r_j) \quad (4)$$

$$f_j(r_j) = \begin{cases} a_1 - b_1 e^{r_j} & (\text{neutral customer, } t = 1) \\ a + b r_j & (\text{positive customer, } t = 2) \\ a_2 + b_2 e^{r_j} & (\text{conservative customer, } t = 3) \end{cases}$$

$$r_j = \sum_i y_{i,j} \quad (5)$$

$$\sum_i y_{i,j} \leq d_i \quad (6)$$

$$\sum_j y_{i,j} \leq e_i Q_i + I_i \quad (7)$$

$$Q = \sum_i Q_i \quad (8)$$

$$f_j^t(0) = 0, f_j^t(1) = U_{\max} \quad (9)$$

$$y_{i,j}, Q_i \in R^+, i, j \in (1, 2, \dots, n)$$

$\Pi(Q)$  in equality (3) includes five parts: the total profit in the allocation stage, the CLV value, the material and manufacturing cost, the expected failing risk cost, and the holding cost of the residual products.  $a, b, a_1, b_1, a_2, b_2, I_i$  and  $U_{\max}$  are constants.  $f_{i,j}$  is the failure risk of one unit of product  $i$ , which is used to fulfil demand  $j$ , so  $0 \leq f_{i,j} \leq 1$ . Equalities (4) and (9) are the CLV function and the corresponding restraint. Equality (5) is the fulfilled demand  $i$ . Inequalities (6) and (7) are the demand constraint and supply constraint, respectively. Equality (8) states that all the materials are allocated to manufacturers.

#### 4. Model analysis

Substitution in semiconductor industry is very common in practice, because the nature performance of the same type of products even in one batch may be different. But the practice is always hard to describe in mathematical modelling, little has been done on the impact of the demand substitution to the supply chain network. Substitution can help to

remit the bullwhip effect and gives the supply chain with flexibility. A number of papers have studies substitution policy in a product allocation system (Chen & Plambeck, 2008; Shumsky & Zhang, 2009). The dissertation applies and studies the impact of the demand substitution to a semiconductor supply chain network.

In this manufacture and allocation system, the whole rotation can be divided into two stages: the production stage and the allocation stage (see figure 1). At the production stage, the supplier determines the optimal materials input, while at allocation stage the manufacturers allocate the products. The allocation policy determines not only the revenue of the allocation stage, but also the materials inputs at the production stage.

Let  $N$  be the difference between the actual demand and available product, then we have:

$$N = (N_1, N_2, \dots, N_n) = ((e_1 Q_1 + I_1 - d_1), (e_2 Q_2 + I_2 - d_2), \dots, (e_n Q_n + I_n - d_n))$$

Obviously,  $N_i$  ( $i = 1, \dots, n$ ) can be positive, negative, or zero. For  $i = 1, \dots, n$ , if  $N_i^t > 0$  and  $N_j^t < 0$ , then  $y_{i,j}$  units of product  $i$  can be offered for upgrading. The realized upgraded quantity is non-negative and does not exceed the quantity that product  $i$  can provide. That is,

$$0 \leq y_{i,j} \leq \min(|N_j|, N_i)$$

Single-step upgrade can deliver most of benefit of more complex substitution schemes (Jordanand 1995) and some literatures consider the single-step upgrade as the optimal allocation policy (Shumsky & Zhang, 2009). The single-step upgrade allocation policy states that the substitution can be allowed between two neighbour product classes where the high class products are in stock (see figure 6.).

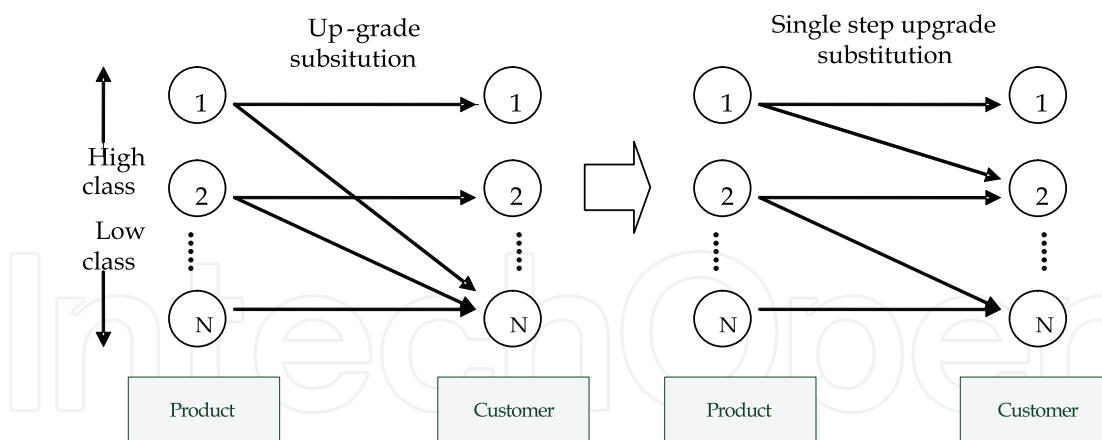


Fig. 6. Single step upgrade substitution

**Proposition 1.** Traditional substitution policy is not the optimal allocation policy of the integrated system.

In our paper, we take customer life time value in to account as one evaluation indicator when make allocation decisions. When  $N_i^t > 0$ ,  $N_j^t < 0$ ,  $i < j$ , and  $N_{j+1}^t < 0$ , we may choose the residual quantity product  $i$  to satisfy the demand class of  $j$  or demand class  $j+1$  or even both the demands, but the puzzle is that which is the optimal choice of the three substitution policies. Based on equation (2), the difference between contribution margin  $\alpha_{i,j}$  and contribution margin  $\alpha_{i,j+1}$  are,

$$\begin{aligned}
\Delta\alpha &= \alpha_{i,j} - \alpha_{i,j+1} \\
&= (p_i + v_i - u_j + U_j / \sum_i y_{i,j}) - (p_{i+1} + v_{i+1} - u_j + U_{j+1} / \sum_i y_{i,j+1}) \\
&= (p_i - p_{i+1} + v_i - v_{i+1}) + (U_j / \sum_i y_{i,j} - U_{j+1} / \sum_i y_{i,j+1})
\end{aligned} \tag{10}$$

In equality (10),  $\Delta\alpha$  consists of two part, the first part  $p_i - p_{i+1} + v_i - v_{i+1}$  is obviously positive because of equality (1). The values of  $U_j / \sum_i y_{i,j}$  and  $U_{j+1} / \sum_i y_{i,j+1}$  are depend on the customer type and the realized quantity of demand, so we can not estimate the size of the second part of the right-hand-side of equality (10) until the allocation decisions are made. Thus,  $\Delta\alpha$  is not necessarily positive or negative. It means that the traditional single-step upgrade allocation policy is not the optimal in this integrated system.

Lemma 1.  $\Pi(Q)$  is concave in  $Q$ .

Proof. The programming model can be simplified and transformed as,

$$\Pi(Q) = E_{d_1, \dots, d_n, k_j^t} \Pi(Q_i)$$

$$\Pi(Q_i) = \max_{i,j} [(\sum_{i,j} \alpha_{i,j} y_{i,j} - \sum_i v_i d_i) + k_j^t \sum_j f_j^t (\sum_i y_{i,j}) - C \sum_i Q_i - f_{i,j} y_{i,j} - h_i (e_i Q_i + I_i - \sum_j y_{i,j})]$$

s.t.

$$\sum_i y_{i,j} \leq d_i \tag{11}$$

$$\sum_j y_{i,j} \leq e_i Q_i + I_i \tag{12}$$

$$y_{i,j}, Q_i \in R^+, i, j \in (1, 2, \dots, n)$$

$\Pi(Q_i)$  is a linear program model of  $Q_i$  ( $i=1, \dots, n$ ) with the constraints of inequalities (11) and (12). Obviously,  $\Pi(Q_i)$  is concave in  $Q_i$  because a linear program is concave in variables that determine the right-hand-side of its constraints. Van Slyke and Wets (1966) prove that concavity is preserved over the expectation operator, so  $\Pi(Q)$  is concave in  $Q_i$ . Because is a positive linear function in  $Q_i$ , so  $\Pi(Q)$ , as the function of  $Q_i$ , is also concave in  $Q$  (Rockafeller, 1970).

## 5. Solution method and numerical experiment

### 5.1 Solution method

The decision model is a stochastic programming model, the demand distributions for the products are modelled not by their analytic functions but rather by a finite number of randomly generated demand scenarios that are statistically identical to the joint probability distribution of the demands. It should be noted that a finite number of scenarios can model only an approximation of continuous distributions, but that a model with a sufficiently large

number of scenarios can approach the actual distributions. Let  $M$  denote the number of scenarios and superscript each of the following parameters and variables by the scenario index  $m$ :  $d_i^m$  and  $k_j^{tm}$ . Monte Carlo sampling is often used in stochastic linear program to maximize the expected profit over the scenarios. Each scenario may be given a probability weight  $w_m$ .

We now have the following formulation for the problem that models  $d_i^m$  and  $k_j^{tm}$  distributions using the  $M$  scenarios:

$$\begin{aligned} \Pi'(Q) = \max & \left[ \sum_{i,j} \alpha_{i,j} y_{i,j} - \sum_m w_m \left( \sum_i v_i d_i^m \right) + \sum_m w_m \left( k_j^{tm} \sum_j f_i^{tm} \left( \sum_i y_{i,j} \right) \right) \right. \\ & \left. - C \sum_i Q_i - f_{i,j} y_{i,j} - h_i (e_i Q_i + I_i - \sum_j y_{i,j}) \right] \end{aligned}$$

s.t.

$$\sum_i y_{i,j} \leq d_j \quad (13)$$

$$\sum_j y_{i,j} \leq e_i Q_i + I_i \quad (14)$$

$$y_{i,j}, Q_i \in R^+, \quad 0 < m \leq M$$

The solution steps for the objective function (3) are shown in figure 7.

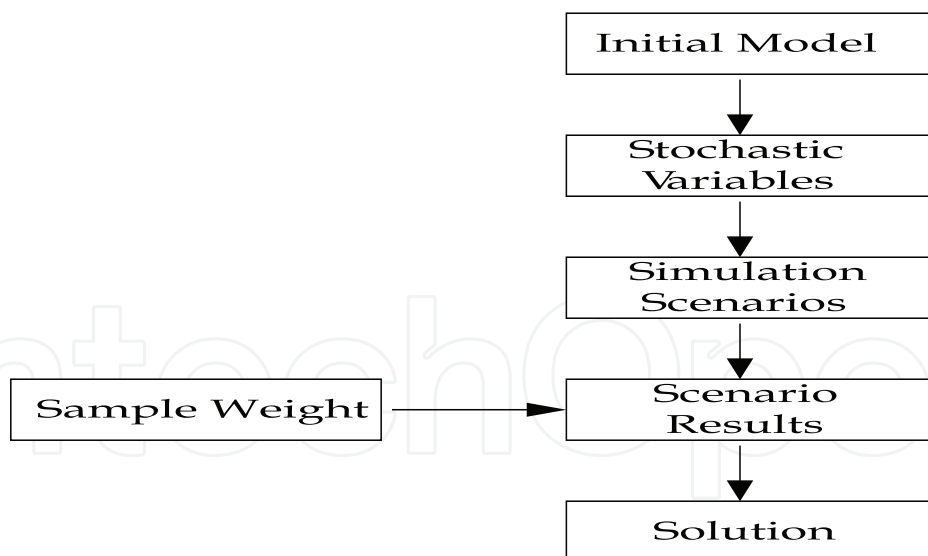


Fig. 7. The solution steps

There are several basic steps to conduct the sample simulation.

- Step 1. Analysis the programming model, and determine the stochastic variables in the model.
- Step 2. Generate the stochastic samples.
- Step 3. Solve the model based on each sample series.
- Step 4. Determine the weight of each sample series.



Step 5. Calculate the optimal value of the decision variables.

In the simulation, the choice of the number of scenarios  $M$  is important when the scenarios in the model can only approximate the demand distributions. As the value of scenarios  $M$  increase, there is a trade-off between the increased computing time and the improved accuracy as a result of a better approximation of the model.

5.2 A simple numerical experiment

Using the above formulation, we can obtain an optimal material quantity and the optimal capacity of each manufacture by solving the program. As an example, we consider a problem with five products ( $n=5$ ) and the following are the parameters (see table 3.):

Product	$p_i$	$v_i$	$e_i$	$h_i$	$I_i$	$u_i$
1	7	13	20	7	22	0.5
2	6	10	24	4	34	0.43
3	5	8	32	6	21	0.39
4	4	7	31	3	41	0.35
5	3	5	27	5	32	0.25

Table 3. The values of parameters

We assume  $a=3$ ,  $b=2.4$ ,  $C=2.3$ ,  $M=5000$ ,  $w_m=1$ . The value of  $f_{i,j}$  is shown in table 4.

	Demand 1	Demand 2	Demand 3	Demand 4	Demand 5
Product 1	0.01	0.02	0.021	0.024	0.028
Product 2		0.012	0.023	0.024	0.027
Product 3			0.01	0.013	0.017
Product 4				0.012	0.021
Product 5					0.009

Table 4. The value of  $f_{i,j}$

In this example, we assume that the demands are normally distributed with the given mean and standard deviation:  $d_1 \sim n(34,42)$ ,  $d_2 \sim n(53,69)$ ,  $d_3 \sim n(52,18)$ ,  $d_4 \sim n(73,37)$   $d_5 \sim n(64,15)$ . We also assume  $k_j^1$  ( $j=1,2,3,4,5$ ) follows beta distribution, and  $k_i^{tm}$  is generated as follows (table 5.):

	$k_1^t$	$k_2^t$	$k_3^t$	$k_4^t$	$k_5^t$
$t=1$	$B(3,5)$	$B(4,7)$	$B(4,6)$	$B(5,4)$	$B(4,4)$
$t=2$	$B(2,4) * k_1^1$	$B(2,2) * k_2^1$	$B(5,4) * k_3^1$	$B(2,9) * k_4^1$	$B(7,2) * k_5^1$
$t=3$	$1 - k_1^1 - k_1^2$	$1 - k_2^1 - k_2^2$	$1 - k_3^1 - k_3^2$	$1 - k_4^1 - k_4^2$	$1 - k_5^1 - k_5^2$

Table 5. The value of  $k_i^{tm}$

As has been studied in the theory of Monte Carlo sampling, 5000 iterations of simulation is enough to get a relatively accurate result. After 5000 iterations, we get the optimal material quantity  $Q=136.29$ . The optimal capacity of manufacturers are  $Q_1=18.23$ ,  $Q_2=24.72$ ,  $Q_3=26.58$ ,  $Q_4=29.15$ ,  $Q_5=37.61$ .

## 6. Conclusion

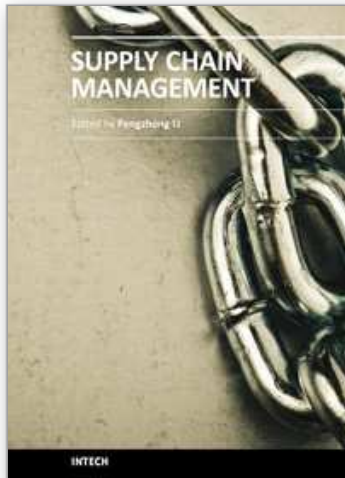
In this work we study a capacity determination problem of the manufacture and allocation integrated supply chain in semiconductor industry. The material supplier invests in materials (e.g. silicon) before the actual demands are known. All the manufacturers produce one type of output, but the nature performances of the outputs produced by different manufacturer are distinctive because of the different technical and equipment conditions. The outputs are classified to different products by the nature performances and then allocated to customers. Customers can be divided into three types (the positive customers, neutral customers and the conservative customers), and their long-term profit functions are different. The demands can be upgraded when a particular type of the product has been depleted. We show that the traditional one-step substitution policy is not the optimal in our system, and we prove that the objective function of the stochastic model is concave in material quantity and the manufacturer's capacity. A solution method of the model is proposed and tested by numerical experiment.

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The purpose of supply chain management is to make production system manage production process, improve customer satisfaction and reduce total work cost. With indubitable significance, supply chain management attracts extensive attention from businesses and academic scholars. Many important research findings and results had been achieved. Research work of supply chain management involves all activities and processes including planning, coordination, operation, control and optimization of the whole supply chain system. This book presents a collection of recent contributions of new methods and innovative ideas from the worldwide researchers. It is aimed at providing a helpful reference of new ideas, original results and practical experiences regarding this highly up-to-date field for researchers, scientists, engineers and students interested in supply chain management.

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