Technology Migration Determination Model for DRAM Industry

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Abstract: Due to short life cycle of DRAM industry over the past decade, the product generation and technology migration have to be quickly enhanced. When technology migration occurred, DRAM companies always used the past experiences to proceed with process changes. However, the issues are totally different particularly in the best practice of technology migration that caused the companies suffered many uncertainties. In this work, a model to determine the timing of technology migration is proposed. The model is based on technology roadmap to set the timing of migration under maximum profit condition. A stable growth trend is assumed for market demand to decide the revenue. Furthermore, the time-cost function of new generational equipment and the theory of learning curve are introduced as the factors to determine the manufacturing cost and profit. Consequentially, the best timing is determined with maximum profit.

1 INTRODUCTION

DRAM industry is a capital intensive, high-tech industry with complex processes and technology migration for DRAM manufacturers has been a very challenging aspect and more time consuming. Since there is no any physical capacity expansion over the past 5 years in Taiwan, all DRAM manufacturers were relying more than ever on technology migration to increase supply and reduce cost. Furthermore, product generation and technology had been quickly enhanced due to short product life cycle. When new technology emerges, it reveals that a lower cost and more effective operation model emerged (Cainarca, 1989). Simultaneously, it also means the current competitive advantages of the company will be jeopardized (Hastings, 1994). Under this circumstance, manufactures have to launch new technology and retrofit generational equipment to meet the market demand and reduce manufacturing cost. Chou et al., (2007) pointed out the technology life cycle of semiconductor manufacturing usually won't be over three years and the time of technology generational transition should take about nine months. Therefore, the semiconductor manufacturers always face the dilemma between capacity expansion and new technology migration. Generally, the major competition factor of DRAM industry is the manufacturing cost. That is why the frequency of technology migration is higher than foundries.

There are many researches regarding to the influence of new technology introducing. Chand and Sethi based on the enhancement of process stability by the new generational equipment to plan the replacement of new generation capacity. However, the impacts on the other factors and the lead time of replacement were not taken into account. Cohen and Halperin proposed a method to determine the timing of technology migration which was based on the price changes of new equipment as well as its impact on the cost to find the best timing for migration. Rajagopalan et al. combined the above two studies and proposed a capacity planning model under the impact of technology evolution. The linear programming was applied and the concept of timeline was added to the decision of capacity expansion or replacement decisions. Pak et al., (2004) proposed a methodology of capacity planning which focused on the capacity shortage to plan the capacity requirement and the influence from cost of new technology capacity was taken into account. Furthermore, the sensitivity analysis was applied to determine how sensitive of this plan in the changes of market demand. Chien and Zheng, (2002) proposed a mini–max regret strategy for capacity planning under demand uncertainty to improve capacity utilization and capital effectiveness in semiconductor manufacturing. Seta et al. studied optimal investment in technologies characterized by

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the learning curve. They emphasized that if the learning process is slow, firms invest relatively late and on a larger scale. If the curve is steep, firms invest earlier and on a smaller scale. It is obvious that most of these researches focused on the market demand to decide the timing of technology migration. However, the market demand is full of uncertainties and hard to handle. Therefore, there will be great difficulty in the practical applications.

The purpose of this work is to propose a model to determine the timing of technology migration. The model is based on technology roadmap to set the timing of migration under maximum profit condition. A stable growth trend is assumed for market demand to decide the revenue. Furthermore, the time-cost function of new generational equipment and the theory of learning curve are introduced as the factors to determine the manufacturing cost and profit. Consequentially, the best timing is determined with maximum profit.

2 TECHNOLOGY MIGRATION DETERMINATION MODEL

The purpose of technology migration is to make more profit for the company. Under the assumption of demand stable growth, the best timing of technology migration is the time which can make the maximum profit for the company. Based on the literature review and market survey, the trend of DRAM unit cost and market price is as Fig. 1. Because the equipment depreciation and product yield is stable under the current production status, the production cost of per giga bit DRAM is almost the same. However, the market price will be dropped off due to the business strategy, new product or technology emerged. The trend of market price can be gotten from history data. Regarding to the unit cost produced by new technology, it will be higher

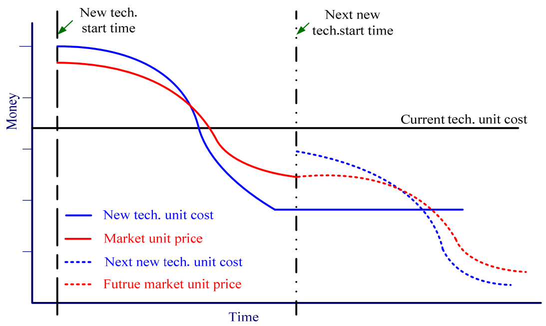

Figure 1: The relationship between unit cost and unit price of per giga bit DRAM.

than current mature technology due to the higher price of new equipment and lower yield of production in the beginning. However, the yield will be improved after a period of time and the unit cost also can be dropped off and even lower than the product from current technology. Based on the abovephenomena, it shows that the best timing of technology migration will be occurred between the emerged time of new technology and the next generation technology.

In order to analyse and establish the model easily, we called the horizon between the emerged time of new technology and the next generation technology as the life cycle of new technology and divided it into n periods. The profit function is established as Eq. 1 and there are three parts, total revenue, total manufacturing cost and the income of equipment disposal, included. The details are described in the follows.

$$TP(t) = (R_{g-1} + R_g) - (\sum_{i=1}^{t-1} (FC_{g-1} + VC_{g-1}) - \sum_{i=t}^{n} (FC_{g,i} + VC_{g,i})) + I_{g-1,t} \quad (1)$$

Where

$TP(t)$:	Total profit which the technology migrated from *t* period
t :	The time of technology migration
R_j :	Revenue of *j* generation technology
$FC_{g,i}$:	Fixed cost of *g* generation technology per period which is migrated at *i* period
FC_{g-1} :	Fixed cost of *g-1* generation technology per period
$VC_{g,i}$:	Variable cost of *g* generation technology per period which is migrated at *i* period
VC_{g-1} :	Variable cost of *g-1* generation technology per period
$I_{g-1,t}$:	The income from the deposal of *g-1* generation equipment at *t* period

2.1 The Function of Total Revenue

The environment of supply demand balance is an assumption of this work. Therefore, all products can be sold by market price. The total revenue means the revenue of n periods. If the new technology is migrated at t period, the revenue from current technology will be the revenue from period 1 to period t-1 and the revenue from new technology will be from period t to period n. Down below is the equation of current technology revenue andnew technology revenue.

2.1.1 The Revenue from Current Technology

If the current technology is not eliminated after new technology emerged, the current technology is still under production. Because the current technology is under a stable stage, the market price and production quantity of the company will keep almost the same. Therefore, the revenue from current technology is established as follows.

$$R_{g-1} = \sum_{i=1}^{t-1} \left(P_{g-1} \times Q_{g-1,i}\right) \tag{2}$$

Where

P_{g-1} :	The average market price of *g-1* generation technology
$Q_{g-1,i}$:	The total quantity of *g-1* generation technology at period *i*

2.1.2 The Revenue from New Technology

The calculation of the revenue from new technology is still formula by the price multiplying the quantity. Due to the new technology belonging to the growing stage, the market price and production quantity of the company will be changed by time. Based on the historical data analysis, the market price can be modelled as a Sigmoid function. The output of Sigmoid function is between 0 and 1. Therefore, the managers should forecast the rate of price change and the saddle point of price curve. Besides, the normalization is used to fit the actual DRAM price. Regarding to the production quantity, due to the unfamiliarity of new technology process, the yield of products will be lower in the beginning. After a period of time, the yield can be improved and products quantity will be increased as well. This concept is similar to the learning curve. Therefore, the concept of learning curve is applied to model the production quantity of new technology. The equation of the revenue from new technology is as follows.

$$R_g = \sum_{i=t}^{n} \left(P_{g,i} \times Q_{g,i}\right) \tag{3}$$

$$P_{g,i} = X \times \left(P_{g,Max} - P_{g,Min}\right) + P_{g,Min} \tag{4}$$

$$X = \frac{1}{1 + e^{a(i-T)}} \tag{5}$$

$$Q_i = IQ \times \left(1 - \left(NP_t \times (i - t + 1)^{\frac{logc_1}{log2}}\right)\right) \tag{6}$$

Where

$P_{g,i}$:	The average price of g generation technology at *i* period
$P_{g,Max}$:	The maximum price of g generation technology
$P_{g,Min}$:	The minimum price of g generation technology
X :	The normalization value of Sigmoid function
a :	The rate of price change
T :	The saddle point of Sigmoid function
Q_i :	Production quantity at *i* period
IQ :	Release quantity per period
NP_t :	The initial failure rate of new technology
c_1 :	The learning rate of production failure rate, set by the managers

2.2 The Function of Total Cost

As the characteristics of DRAM industry, the company can get more profit from new generation technology. However, a huge of cost should be paid for new generational equipment behind profit. This cost is called as capacity acquired cost. Therefore, the calculation of production cost can be divided into two part, fixed cost and variable cost. The fixed cost is the cost of equipment for new technology and the depreciation of current equipment. There is no depreciation for the deposal equipment. The variable cost is the expense for the production. The details are as follows.

2.2.1 Fixed Cost of New Technology

Due to the migration to new generational technology, the new generational equipment is required. Generally, the price of new generational equipment will be reduced by time. In this work we assume the price will be linear decreasing. Besides, the required equipment quantity depends on its throughput. Based on these concepts, the fixed cost is formulized as follows.

$$FC_i = \left(\frac{MP_{g,i} \times x_{g,i}}{m} - RFC_{g-1}\right) + FC_{g-1} \tag{7}$$

$$MP_{g,i} = MP_{g,0} - D \times (i - 1) \tag{8}$$

$$D = \frac{MP_{g,0} - RV_g}{m} \tag{9}$$

$$x_{g,i} = \left\lfloor \frac{C_{g-1} \times x_{g-1}}{C_g} \right\rfloor + 1 \quad (10)$$

$$C_g = MP_g \times CP_g \times ICC_g \quad (11)$$

Where

$x_{g,i}$: The quantity of generation *g* equipment which purchased at *i* period

D : The reducing value of equipment per period

$MP_{g,i}$ The price of generation *g* equipment which purchased at *i* period

RFC_{g-1} The fixed cost of generation *g-1* equipment which is disposed at period t

RV_g : The residual value of generation *g* equipment

m : Numbers of depreciation period

C_g : The capacity of generation *g* equipment

MP_g : The wafer numbers which producing by the generation *g* equipment

CP_g : The numbers of IC which producing by the generation *g* equipment

ICC_g : The memory size per die which producing by the generation *g* equipment

2.2.2 Variable Cost of New Technology

Generally, the variable cost of production will decrease as the yield increase. The yield increasing is the result of the mature of co-operating in man-machine and the accumulation of engineer's experiences. Therefore, the variable cost will present same as the concept of manufacturing progress function and it is applied in the formulation of variable cost.

$$\mathrm{VC_{g,i}} = \mathrm{C_t}(\mathrm{i} - \mathrm{t} + 1)^{\frac{\log c_2}{\log 2}} \quad (12)$$

Where

C_t : The variable cost which the migration occurred at *t* period

c_2 : The learning rate of variable cost, set by the managers

2.3 The Income from the Disposal of Equipment

The equipment which cannot process the new generation technology will be disposed. The income from the disposal of equipment is as the following equation.

$$I_{g-1,t} = MP_{g-1,t} \times y_{g-1,t} \quad (13)$$

Where

$MP_{g-1,t}$: The price of *g-1* generational equipment at *t* period

$y_{g-1,t}$: The equipment quantity of *g-1* generational equipment

3 NUMERICAL EXAMPLE

Here, a numerical example is illustrated to demonstrate the modelling and determination process of the proposed model. The environment of this example is a 300mm DRAM fab with 30K wafers per month. The major product is DDRII and 1300 chips per wafer. New generation technology is DDRIII and 1800 chips per wafer. The sales quantity is equal to the production quantity under the assumption of strong market demand condition. Besides, the duration of period is one month and all cost, price and revenue are counted by US dollar. The following is the detailed modelling and determination process. Furthermore, t=8 is assumed for all calculation.

3.1 Total Revenue

3.1.1 The Revenue from Current Technology

Assume the price of current technology is \$0.8 per giga bit and production yield is 0.98. Therefore, the revenue from current technology is as follows.

$$\mathrm{R_{g-1}} = \sum_{\mathrm{i}=1}^{7} (1.2 \times 1300 \times 30\mathrm{K} \times 0.98) = 45{,}864{,}000 \times 7 = 321{,}048{,}000$$

3.1.2 The Revenue from New Technology

Regarding to the price of DDRIII, the data from Aug. 2009 to July 2012 is collected to formula the Sigmoid function. Assume the parameters of Sigmoid function T is 16 and a is 0.3. The maximum and minimum price of DDRIII is 2.5 and 1.2. The price of new technology is as follows.

$$\mathrm{X} = \frac{1}{1 + \mathrm{e}^{0.3 \times (8-16)}} = 0.9168$$

$$\mathrm{P_{g,8}} = 0.9168 \times (2.5 - 1.2) + 1.2 = 2.3918$$

Due to the improvement of product yield, the production quantity will increase. Assume the product yield is 0.45 in the beginning of migration and c_1 equals to 0.85. The production quantity of period 8 is calculated as follows.

$$Q_{g,8} = 54{,}000K \times \left(1 - \left(0.55 \times (8-8+1)^{-0.2345}\right)\right) = 23{,}220{,}000$$

$$a_1 = \frac{\log 0.9}{\log 2} = -0.152$$

The revenue from new technology is as follows.

$$R_g = \sum_{i=8}^{36} (P_{g,i} \times Q_{g,i}) = 1{,}504{,}087{,}017$$

3.2 Total Cost

3.2.1 Fixed Cost

Assume the depreciation for equipment is six years. Three sets of g-1 generation should be replaced and their original cost is 0.1 billion. Total equipment cost of old technology excluding the disposals is 2 billion. The parameters of product by new and old technology are as follows.

ICC_g=1GB, CP_g=1800, MP_g=10000
ICC_{g-1}=1GB, CP_{g-1}=1300, MP_{g-1}=10000

Therefore, C_g and C_{g-1} equals to 18,000,000 and 13,000,000. The new generational equipment quantity can be determined by Eq. 10.

$$x_g = \left\lfloor \frac{13000000 \div 0.98 \times 3}{18000000 \div 0.61} \right\rfloor + 1 = 3$$

Assume the price of new generational equipment is 1 billion per set in the beginning and its residual value is 0.2 billion. Therefore, if the new generational equipment is purchased at period 8, its price is calculated as follows.

$$D = \frac{100{,}000{,}000 - 20{,}000{,}000}{72} = 1{,}111{,}111$$

$$MP_{g,8} = 100{,}000{,}000 - 1{,}111{,}111 \times 7 = \$92{,}222{,}222$$

Based on the assumptions above, the total fixed cost is calculated as follows.

$$FC_{g,8} = \frac{92{,}222{,}222 \times 3}{72} + \frac{2{,}000{,}000{,}000}{72} = 31{,}620{,}370$$

$$\sum_{i=1}^{7} FC_{g-1,i} + \sum_{i=8}^{36} FC_{g,i} = 1{,}121{,}157{,}407$$

3.2.2 Variable Cost

Assume c_2 = 0.82, C_t=10,600,000 and $VC_{g-1,i}$=7,141,000

Then $a_2 = \log 0.82 / \log 2 = -0.377069649$

$$VC_8 = 10{,}600{,}000(8-8+1)^{-0.377069649} = 10{,}600{,}000$$

$$\sum_{i=8}^{36} VC_{g,i} = 156{,}956{,}539$$

The following is the calculation of total variable cost.

$$VC = \sum_{i=1}^{7} VC_{g-1,i} + \sum_{i=8}^{36} VC_{g,i} = 7{,}141{,}000 \times 7 + 156{,}956{,}539 = 206{,}943{,}539$$

The total cost is fixed cost plus variable cost.

$$\text{Total Cost} = 1{,}121{,}157{,}407 + 206{,}943{,}539 = 1{,}328{,}100{,}946$$

3.3 The Income from the Disposal of Equipment

Assume the disposal equipment has been purchased for 47 months at the time of new technology emerged. Therefore, the total value at the period 8 is as follows.

$$I_{g-1,8} = \left(\frac{\frac{100{,}000{,}000 \times 0.8}{72} \times 17 + 100{,}000{,}000 \times 0.2}{3}\right) \times 3 = 38{,}888{,}888$$

3.4 Total Profit

Finally the total profit is as follows if the technology migration occurred at period 8.

$$TP(8) = (321{,}048{,}000 + 1{,}504{,}087{,}017) - 1{,}328{,}100{,}946 + 38{,}888{,}888 = 535{,}922{,}959$$

Based on the above calculation, the relationship of total profit vs. the migration time t is shown as Fig. 2.

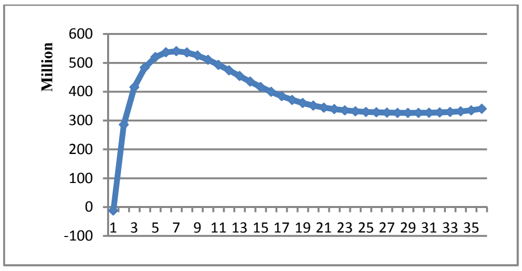

Figure 2: The relationship between total profit and migration time *t.*

The best time for generational transition can be determined as period 7 from Fig. 2.

4 CONCLUSIONS

DRAM industry is a capital intensive, high-tech industry and the product generation has been quickly enhanced. Due to the huge investment for the technology migration, the migration timing is very important for the company. In this work, a model to determine the best timing for the technology migration is established. The maximum profit is the objective to determine the migration time in the model. All revenue and cost of technology migration are considered. We expect this model can be applied in other industries with same situation.

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