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Research on Countermeasures to Economic Challenges Faced by Enterprises in the Environment of Semiconductor Industry
A Case Study of ABCtronics

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ABSTRACT
In 2021, IC chips are in extreme shortage in many factors. The companies in the semiconductor industry are facing various problems: high production costs, unsatisfying the high demand, and so on. However, difficulties create opportunities and innovation. In facing the big data and new information era, difficulties can devastate a company and make a company. In this research, we analyze a virtual company in the semi-conductor from the business and the statistic angles to solve the main problems they meet and make correct decisions for changing the business model. The virtual company and the data resource are from Case ABCtronics. The main methodology is using statistical distribution to analyze the data from the company and make decisions for improving the company's utility and efficiency in two dimensions: production and sales. This paper eventually concludes with the better approaches of controlling production cost, quality control of IC chips, and serving customers.

Keywords- *semiconductor industry; business analytics; data analysis; probability distribution*

1. INTRODUCTION

1.1. Research Background and Motivation

The semiconductor industry has had significant growth since the initial development of the whole industry, driven by multiple demands. With the increasing demands of seeking convenient and intelligent life, semiconductors exist everywhere in our daily lives, bringing happiness and improving life quality. The most useful intelligent device, the smartphone, is indispensable because it basically helps people contact each other. In advance, it helps us obtain plenty of data in this world. What all its functions are mainly set by the chip in the phone, like the "brain" of the phone, which is made by the semiconductor. Nowadays, the semiconductor is used in numerous products in manufacturing industries, such as computers, automobiles, artificially intelligent robots, etc. The 21st century is called "the Age of Big Data", and people know everything once they can obtain the data. The semiconductor enables humans to achieve this, which is the acquisition of data. With the progress of 5G communication technology, the economic entity formed by the communication products industry chain ballooned since people started knowing it in 2016. By following the era of 5G, an increasing number of countries are dedicated to the research and development of 5G. In need of supporting more advanced devices supporting 5G, some companies develop the chips that can connect to the 5G high-speed transmission by themselves, like Qualcomm and Huawei. However, the 5G trend and research and development process indicate many challenges to the semiconductor manufacturing companies.

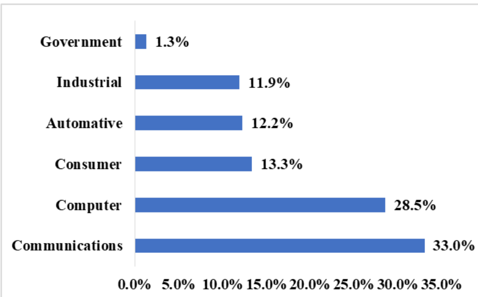

Figure 1 The total global semiconductor demand share by end use in 2019

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The demand for semiconductors is not always tremendous. The periodicity of the demand for semiconductors is relatively longer than other products. For instance, people usually use a smartphone for about two years. In the two years, the person will not buy one new smartphone since he bought it. Microscopically, the semiconductor manufacturing company that supplies the chip to the smartphone company loses 1 quantity demanded in the two years. Macroscopically, there are approximately 7 billion people in this world. If only 5% of them buy this smartphone when it comes up to the world, the company that produces the chips loses 350 million quantities demanded in the next two years. Furthermore, due to the hot trend of producing chips in the semiconductor industry, many companies are increasing. Supplying for a company that needs chips to produce intelligent devices is challenging. Besides, Moore's Law is perishing. As Gordon Moore said, the number of transistors that can be accommodated on integrated circuits doubles about every 18 months. Applying this law to Intel, we say that the performance of a processor doubles about every 2 years. Now, economically, more advanced and sophisticated manufacturing procedure needs substantial investment. It is risky for companies and investors to undertake the risks because they probably cannot get the money they invested back to their wallets and let the profit alone. Technically, the limitations of the manufacturing procedure are extremely difficult to break through, including photoetching, quantum effect in device physics, the parasitic effect of interconnection, power dissipation, path latency, packaging etc. Hence, nobody knows when Moore's Law disabled, but everybody working in a semiconductor company knows they have problems. Therefore, a semiconductor manufacturing company needs to improve the productivity to satisfy the demand of its clients in the period of economic growth; also, they need to solve the problem caused by the excess production capacity and high costs in the period of economic slowdown.

ABCtronics is a virtual company in ABCtronics: Manufacturing, Quality Control, and Client Interfaces (2016). It is a semiconductor manufacturing company established in 1997. To explore the challenges of the semiconductor manufacturing companies in the background of the competitive semiconductor industry, this research analyzes the circumstances and difficulties that ABCtronics is facing by using the statistics approach. Albeit there are some plans proposed in the original paper, some problems still need to be solved.

1.2. Literature Review

First, all the data and information about ABCtronics is derived from the paper, ABCtronics: Manufacturing, Quality Control, and Client Interfaces, written by A. Adhikari, I. Biswas, and A. Bisi [1]. Secondly, G. E. Moore in No Exponential is Forever: but "Forever" can be delayed! [semiconductor industry] discussed the development trend and future challenges of the semiconductor industry by analyzing the characteristics of the semiconductor market and studying the parameters related to the industry [2]. Hee-Woon Cheong, in his paper Management of Technology Strategies Required for Major Semiconductor Manufacturer to Survive in Future Market, studies the competition in the global semiconductor market and the transformation and promotion strategies of semiconductor companies so that they can survive in the industry by discovering the problems in the global semiconductor market [3]. These two papers provide the background and circumstances of the competitive semiconductor industry nowadays. Furthermore, the paper of J.-Emeterio Navarro-Barrientos, Characterization and analysis of sales data for the semiconductor market: An expert system approach, through qualitative data mining, an expert system is established to predict the purchasing behavior of semiconductor market by using the characteristics of chip purchasing policy: similarity measure and probability rule [4]. This paper also analyzes the data of the semiconductor industry using statistical methods. In Brittany Bagley's Semiconductor financing: Recent trends, he obtained the financing trend and innovative financing mode of the semiconductor industry in the future by studying and analyzing the history and various factors of the semiconductor industry [5]. Moreover, Braha and Shmilovici, in their paper, Data mining for improving a cleaning process in the semiconductor industry, integrate the data from the information on chip manufacturing, which was then mined using IFN methods to predict production line yields and flow time classification models, and finally critically evaluated [6]. Then, we have Pengfei Tong's paper, Fault detection for semiconductor quality control based on Spark using data mining technology, which discusses how to apply data mining to quality control of semiconductor manufacturing process, and compares the effectiveness of two data mining algorithms (SVM and Random Forest) for semiconductor quality control by proposing and completing a complete semiconductor quality control program [7]. These two papers provide the current IC chips quality control cases and are comparable to ABCtronics' quality control methods. Besides, S.Bittanti, in his paper, Application of non-normal process capability indices to semiconductor quality control, introduced the curve fitting method and application examples to provide a confidence interval for PCI estimation and solve the problem of defining and calculating a reliable estimation of process capability index for non-normal processes [8]. In the paper Improved customer satisfaction with a hybrid dispatching rule in semiconductor back-end factories, David M. Chiang used fuzzy analytic hierarchy process (AHP) to determine the appropriate, acceptable WIP deviation level to determine the operational priority and constructed a model using real data to examine and propose mechanisms to improve customer satisfaction [9]. Then, in Chieh-Min Chou's paper, how does manufacturing service perceived value influence customer satisfaction? In an investigation of the global semiconductor industry, the author proposed a model to hypothesize and statistically analyze the relationship between test value drivers and customers' perceived value of semiconductor manufacturing services and the impact of perceived value on customer satisfaction [10]. The research shows that perceived value and value drivers are different among services, and the impact of line service on customer satisfaction is more significant than that of support service. Eventually, in What the semiconductor industry tells us about the world economy, The Economist discussed the influences of different economic and market changes on the semiconductor industry and the information of global market economy reflected by the development of the semiconductor industry, which predicts the future circumstance in the semiconductor industry; hence makes more convenient to analyze ABCtronics in multi-dimension perspectives [11].

1.3. Research Contents and Framework

This research proposes the plan of optimization in producing the chips and the development by analyzing the circumstance of the semiconductor industry and the current situation and problems of ABCtronics. The framework is the introduction, theorem, methodology, the result and discussion of analyzing the theorem and methodology, and finally, the conclusion.

2. THEOREM AND METHODOLOGY

2.1. Downtime Problem

ABCtronics received complaints from the main clients, XYZsoft. There are four significant problems they need to solve: the improvement of operation efficiency, the reworking, the feedback of their customers, and the sales growth potential.

First of all, the downtime of the ion implanter causes them to produce only 500 IC chips per lot. Ion implantation can cause nuclear transformation or change the crystal structure of some solid materials, which is widely used in semiconductor manufacturing. The minimizing of the downtime of the ion implanter improves the work efficiency. According to Stuart, the average downtime is 6 hours currently, and they need to cut it down to 5 hours. Nevertheless, regarding the analysis of downtime of ion implanter and whether changing the machine or not, two staffs of ABCtronics differ in their opinion. Mark proposes that the downtime follows the gamma distribution, while Stuart insists on the uniform distribution. The different properties of these distributions can explain the reason. Mark believes that the individual probability of downtime follows the exponential distribution, and the overall probability obeys the gamma distribution. However, Stuart thinks the probability of the downtime is the same on every time point. In deciding whether to replace the ion implanter to minimize the downtime, we can calculate the probability of that less than or equal to 5, $P(t \leq 5)$, by using these two distributions.

Gamma distribution is a two-parameter family of continuous probability distributions. Assuming that the random variable x is the waiting time for the α event to occur, the probability density function can be given by:

$$f(x;k,\theta) = \frac{x^{k-1}e^{-\frac{x}{\theta}}}{\theta^k\Gamma(k)}, x, k, \theta \in \mathbb{R}^+ \quad (1)$$

and the expected value and the variance of a random variable X under gamma distribution are given by:

$$E(X) = k\theta \quad \text{and} \quad Var(X) = k\theta^2 \quad (2)$$

In this case, we can use the sample mean and variance to estimate the population parameters. The sample mean is 6 hours, and the variance is 3 hours.

Table 1. Data on downtime with calculated mean and variance

Month	Downtime (in hours)
July, 2012	3.36
August, 2012	4.48
September, 2012	4.36
October, 2012	6.40
November, 2012	5.24
December, 2012	5.40
January, 2013	7.20
February, 2013	9.24
March, 2013	8.40
April, 2013	5.06
May, 2013	6.20
June, 2013	4.40
Mean	5.88167
Variance	3.0748

For gamma distribution, we put the figures into the formula of E(X) and Var(X):

$$E(X) = k\theta = 6$$

$$Var(X) = k\theta^2 = 3$$

$$k = 12$$

$$\theta = \frac{1}{2}$$

Now, we directly use the Excel function GAMMA. DIST(5,12,0.5,1) = 0.303, which means there is merely 30% chance to make the downtime under 5 hours.

If a continuous random variable X follows the uniform distribution, then its probability density function is given by:

$$f(x:a,b)=\frac{1}{b-a}\ ,a\leq X\leq b \qquad (3)$$

The expected value and the variance of a random variable X under uniform distribution can be expressed as:

$$E(X)=\frac{b+a}{2}\quad and\quad Var(X)=\frac{(b-a)^2}{12} \qquad (4)$$

In this case,

$$E(X)=\frac{b+a}{2}=6$$

$$Var(X)=\frac{(b-a)^2}{12}=3$$

$$a=3$$

$$b=9$$

Hence, the probability is $\frac{(5-3)}{(9-3)}=\frac{1}{3}=$ 33%, which is quite similar to the probability of gamma distribution. Therefore, it is confident that the probability of achieving 5 hours for the ion implanter is only approximately 0.3, which is too low to satisfy their goal. The machine should be replaced with a more efficient one.

2.2. Comparison of Quality Control Method

Producing IC chips cost a company a lot. Also, the probability of producing defectives increases with the growth of complexity in designing the IC chips. Currently, many companies are using data mining to control the quality of the chips, which collects and post-process the data and build models for predicting line yield and flow times. However, in the case of ABCtronics, they are using the Lot Acceptance Testing Method (LATM) for checking quality. Still, the quality control team of ABCtronics proposed a new a new quality control method, ICTM which is called Individual Chip Testing Method. The board is deciding whether to approve this quality control method or not. Besides, ABCtronics' production data analysis indicates that the probability of producing a defective is 0.004. Now, they are trying to find an approach to decrease it to 0.002. Hence, we need to compare the two policies, find out any flaw in them, and determine whether the new method can achieve at 0.002 probability.

In LATM, the method randomly chooses 25 samples from 500 IC chips without replacement. If the samples include less than 2 defectives, they accept the lot; otherwise, they refuse. Hence, the LATM uses the hypergeometric distribution for randomly drawing a sample without replacement. The probability mass function is given by:

$$f(x;n,N,M)=\frac{\binom{M}{x}\binom{N-M}{n-x}}{\binom{N}{n}} \qquad (5)$$

We can calculate it in Excel by using the function HYPERGEOM.DIST. In this case, we have HYPERGEOM.DIST(1, 25, 2, 500, 1). "1" means that there are one or fewer defectives in the sample; "25" is the sample size; "2" is the average (500×0.004) of defectives in every 500 chips, which is the population of success; "500" is the total population size and the last "1" means that we need to calculate the cumulative probability. Finally, we have the result of 0.9976, which means the probability of success is surprisingly high.

In ICTM, it randomly draws 25 one by one and allows replacement. Once finding the defective, ABCtronics needs to start the reworking process. With a replacement for drawing every chip from the sample, the ICTM used a Poisson distribution, which gives the probability of finding the occurrence of x events in a given period of time when the events are independent and happen at a constant rate, λ. The probability mass function is given by:

$$f(x;\lambda)=\frac{e^{-\lambda}\lambda^x}{x!} \qquad (6)$$

Here, we can also use the Excel function:

$$\mathrm{POISSON.DIST(x, mean, cumulative)}$$

We take and check the chips one by one. Hence x is "1"; the expecting value is "1" (500×0.002); the last "1" means cumulative. The passing rate is approximately 0.7358. Compared with the probability of success of LATM, ICTM is moderately high but not as extremely high as the LATM, which means we can discover more defectives in the ICTM quality control system. Therefore, the flaw of the LATM is that the passing rate is too high to reject a lot for the IC chips.

2.3. Analysis on Client Interfaces

ABCtronics also have problems with the issue of satisfying clients' requirements. The life expectancy probably cannot be used for more than 6 years, but the staff Mark is confident that ABCtronics should be able to meet the requirements. Let's see the Rigorous Testing report, which checks for the lifespan of the products and whether the IC chips meet the expectation of Customer PQR systems.

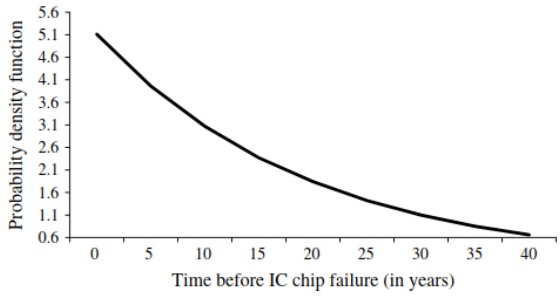

Figure 2 The Rigorous Testing Report on the life expectancy of IC chips

Table 2. Salient data points from the early life failure test

Time before failure (in years)	The cumulative distribution function of failure time
5	22.55
10	40.00
15	53.53
20	64.01
25	72.13
30	78.41

Given the probability density function graph, it is determined as an analysis of the exponential distribution of the time before the failure of IC chips. We found that the reasons why Mark is confident that his company can satisfy the expectation are clear. He must have the resolution that the probability of the time before failure that less than 6 years is small enough. The notes mention that "the time before failure of IC chips is exponentially distributed". An exponential distribution describes the time between events in a Poisson process, which is a special case of the gamma distribution. It is a continuous simulation of the geometric distribution, and it has the key property of no memory. In addition to being used to analyze Poisson processes, it can be found in various other environments. Its probability density function can be expressed as:

$$f(x;\theta) = \frac{1}{\theta} e^{-\frac{x}{\theta}} \quad (7)$$

Where θ represents the scale parameter. Given the cumulative density table above, we have:

$$f(x, \lambda) = 1 - e^{-\lambda x}, x > 0 \quad (8)$$

$$f(5) = 22.55\% = 1 - e^{-5\lambda}, \lambda = 0.05$$

We can bring a random group of time before failure (in years) and cumulative distribution function of failure time and calculate that λ is 0.05. Now, we use the Excel function of exponential distribution and calculate the probability of the time less than 6 years:

$$\mathrm{EXPON.DIST}(6, 0.05, 1) = 0.2592$$

Which is a moderately small probability number. Therefore, Mark is confident that the IC chips of ABCtronics should have approximately 75% (1-25%) probability that could access the requirement of Customer PQR systems.

3. RESULTS AND DISCUSSION

This research analyzes one company in the semiconductor industry in the microscope. The problems ABCtronics met reflect the whole industry circumstance, microscopely. By using statistical distribution models, we found three major problems and effectively solved them. The company needs to focus on merely two important things: producing and selling, and all problems derived from the two parts. To satisfy their clients' requirements and demands in their owned market, they need to guarantee both producing efficiency and production quality. First of all, they need a precise prediction of the downtime of the ion implanter so that they can forecast and calculate the production of IC chips in the future and whether they achieve their clients' requirements or not. By using gamma distribution, we calculate that there is merely a 30% probability for the ion implanter downtime of 5 hours; hence, they cannot take the risk with the fairly low opportunity. Besides, it is critical to decide controlling the quality of IC chips. A splendid controlling system also decides whether their chips achieve the quality requirements. We determined that the ICTM is a more reasonable controlling method by comparing the two different methods, which separately obeys hypergeometric and Poisson distribution. ICTM can discover more defectives, but LATM ignores defectives. Finally, for the part of after-sales service, they need to pay attention to the life expectancy of IC chips. Given the analyzing chart, the data shows it follows an exponential distribution. Fortunately, their chips have a 75% probability of accessing the requirement of PQR systems.

4. CONCLUSION

The main goal of this research is to make a summary of the whole semiconductor industry by analyzing a representative company using the statistical analyzing method and business analytics. The important point is to properly use the data given by the company, precisely judge the data forms, and make the right calculation. We need to decide the statistical distribution of the events and data obeys. Then, according to the calculation and results, we do the business analytics to make the right decision to help the company running to the correct road. This research is based on a virtual company and event in 2016, which lacks authenticity and is not literally real-time. The direction of the research is infinite. IC chips are currently in shortage in 2021 in the background of the new data era, plus the extremely high production cost and plenty of factors. It is still wondering whether there is an appropriate substitution for chips or whether there is a better way to increase production dramatically.

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