Fault Detection in Semiconductor Industry: ABCtronics

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Abstract. The high prevalence of electronic devices over the past fifty years has fueled the extraordinary rise of the semiconductor industry. The manufacture of semiconductor wafers is a time-consuming and delicate process in which defects might arise and cause the failure of the entire circuit. As more complicated devices generate flaws that are tiny and harder to detect [8], innovations in wafer defect inspection technologies are in high demand. Traditional machine learning approaches, such as univariate and multivariate analyses, have been utilized for a long time as a method for developing defect detection models [3][4]. The virtual firm and data resource are provided by case of virtual company ABCtronics. Nonetheless, obstacles provide possibilities for creativity. In the face of the development of technology, a company's troubles have equal potential to completely wipe it out and propel it to success. The focus of this investigation is on the limitations of the technologies currently used in semiconductor manufacture. The research concludes that loyal clients lead to successful businesses.

Keywords: Business Analytics; Semiconductor Manufacturing; Wafer Detect Inspection; Data Analysis.

1. Introduction

1.1 Research Background and history of wafers

Because silicon materials can be grown into large-sized, high-purity crystals with abundant reserves and low prices, along with excellent properties such as unidirectional electrical conductivity, thermal properties, optoelectronic properties, and doping properties, they have become the most widely used and significant materials in the world. Silicon materials can be grown into large-sized, high-purity crystals [6]. components that make up semiconductors. More than ninety percent of the chips and sensors that are currently accessible on the global market for semiconductors are constructed on silicon materials. The term "semiconductor silicon wafer" refers to a wafer that has been sliced very thinly from an ingot of single crystal silicon. Wafers are usually referred to as "silicon wafers." As the fundamental basic product produced by the semiconductor industry, it can provide an important contribution to the expansion of the sector.

The size and manufacturing method of the silicon wafers used in semiconductors are two of the elements that may be used to separate them from one another. In terms of size, it can typically be categorized as 12 inches (300mm), 8 inches (200mm), 6 inches (150mm), 5 inches (125mm), and 4 inches (100mm). Additionally, it can be subdivided into various types, such as silicon grinding wafers, silicon polished wafers, silicon epitaxial wafers, and so on, with silicon polished wafers and silicon epitaxial wafers being the two most common types [8].

Wafers measuring four inches (100 millimeters) in diameter did not begin to establish themselves as the global norm until about the year 1978. Wafers of 125 millimeters (5 inches), 150 millimeters (6 inches), and 200 millimeters (8 inches) were successively made available. The 21st century has given birth to the age of the 300 mm, which is the era in which we are presently living. Wafers with a diameter of 300 millimeters are used in the most modern semiconductor production lines to produce both logic and analogue devices. Wafers with a diameter of 6 and 8 inches are used in manufacturing lines that were built in the 1980s and 1990s. Some older production lines still use wafers with a diameter of 4 inches [6].

1.2 Semiconductor Manufacturing Process

Semiconductors are used in millions of electronic devices in education, research, communications, healthcare, transportation, and energy. Smartphones, mobile, wearable gadgets rely on semiconductors for essential operations and enhanced functionalities, boosting semiconductor and PCB demand. With the increase in processing power and memory, however, the width of semiconductor lines has been limited to certain range. Semiconductor (or silicon-based) integrated circuits play a major role in modern industrial and domestic appliances. The circuits will act as a simple on/off switch in order to do basic calculations. To accomplish virtually fast switching, circuits must be composed of semiconductor material, a substance having electrical resistance between a conductor and an insulator. Semiconductor fabrication involves specialized facilities and multiple stages. Semiconductor manufacture is a complicated process with extensive lead periods needed to offer device capabilities. From basic research to final output, semiconductor manufacture might take three to five years on average [10].

1.3 Literature Review

ABCtronics is a manufacturer of semiconductors founded in 1997. An analysis of how-to better test product quality reveals that adjustments need to be made to the company's inspection techniques and frequency in order to shorten testing times and boost testing precision. It focuses on the present status and issues facing ABCtronics. Even if the original post had certain goals, there are still certain challenges to overcome. As one of ABCtronics' primary clients, XYZsoft, lodged a complaint. They must discover answers to four significant issues: enhancing operational efficiency, reworking, consumer feedback, and the potential for greater sales [1].

By examining the history of the semiconductor business, where ABCtronics is now, and the difficulties it faces, this study presents a plan for increasing the efficiency with which chips are manufactured and developed. The outline begins with an introductory paragraph and continues with the theorem, methodology, results, and evaluation of the theorem and technique.

This research proposes an approach to enhancing chip manufacturing and development by analyzing the existing condition of ABCtronics, in the context of the semiconductor industry, and the company's problems. The framework consists of an introduction, a background, a methodology, results and suggestion of decision-making and the technique, and a conclusion.

2. Methodology

2.1 Downtime problem

Table 1. Detection machine downtime (Photo credit: Original)

July, 2012	3 hours 36 minutes
August, 2012	4 hours 48 minutes
September, 2012	4 hours 36 minutes
October, 2012	6 hours 40 minutes
November, 2012	5 hours 24 minutes
December, 2012	5 hours 40 minutes
January, 2013	7 hours 20 minutes
February, 2013	9 hours 24 minutes
March, 2013	8 hours 40 minutes
April, , 2013	5hours 06 minutes
May, 2013	6 hours 20 minutes
June, 2013	4 hours 40 minutes

Due to the ion implanter's periodic maintenance needs, each batch of integrated IC chips can only produce 500 chips. The semiconductor industry often uses ion implantation. Also, a reduced amount of time on maintenance for the ion implanter is essential for increasing throughput. Stuart suggests lowering the average downtime from the current 6 hours to 5 hours.

Stuart, however, believes that at every time point, the likelihood of downtime is the same. By evaluating the probability of these two distributions, we can decide if ABCtronics should replace the ion implanter to decrease downtime. that it will be less than or equal to 5 [1]. The two-parameter group of continuous probability distributions known as the gamma distribution. Then we can use probability density function:

$$f(x;k,\theta) = \frac{x^{k-1}e^{-\frac{x}{\theta}}}{\theta^k r(k)} \tag{1}$$

$$E(x) = k\theta \ , \ Var(x) = k\theta^2 \tag{2}$$

Now we can calculate the sample mean and variance E(x) = 6, Var(x) = 3, as well as k = 12, θ = 1/2. The Excel function GAMMA is now being used GAMMA. DIST (5,12,0.5,1) = 0.303, indicating that the possibility of keeping the downtime under 5 hours is under 30%. We now know x follows uniform distribution, so that the probability density function is adopted as:

$$f(x;a,b) = \frac{1}{b-a}, \quad a \le X \le b \tag{3}$$

The typical machine downtime should be six hours, however it is evident from the context that ABCtronic only permits three to four hours of machine downtime. If the machine is repeatedly overworked, its productivity will diminish over time. Therefore, I propose that the corporation raise the machine's downtime from three to six hours so that it can deliver the appropriate quality and results.

2.2 Comparison of quality control method

Production of integrated circuit chips is an expensive endeavor for any company. As the process of creating IC chips becomes more intricate, the possibility of creating flawed products also increases. Many companies now use data mining to regulate chip quality by collecting and analyzing data to develop predictive models of production line yield and throughput. When gauging product quality, ABCtronics use a technique called the Lot Acceptance Testing Method (LATM). However, ABCtronics' QC group introduced a novel QC approach they call ICTM (Individual Chip Testing Method). Whether or not to implement this quality assurance strategy is now being discussed by the board. In addition, an examination of ABCtronics' production data reveals a one in a thousand chance of making a defective item.

From 500 IC chips, 25 samples are randomly selected by LATM without replacement. They approve the lot if there are less than two faulty samples among the samples; otherwise, they reject the lot. As a result, the LATM draws a sample at random without replacement using the hypergeometric distribution. The probability mass function:

$$f(x;n,N,M) = \frac{\binom{M}{x}\binom{N-M}{n-x}}{\binom{N}{n}} \tag{4}$$

In Excel, we can use the HYPERGEOM.DIST function as HYPERGEOM.DIST(1, 25, 2, 500, 1). There are 1 defective (represented by a value of 1), the sample size is 25 (representing the total population size), the average number of defectives per 500 chips in the population of successes is 2, and the total population size is 500 (representing the total population size). The overall probability of success is astonishingly high, at 0.9976. Twenty-five are chosen at random in ICTM, and they may be switched out if necessary. ABCtronics must begin the reworking process when the damaged component has been identified. Instead of taking every chip out of the sample, the ICTM relied on the Poisson distribution, which provides the probability of seeing x occurrences in a given time period if the events are independent and occur at a constant pace. Then we can use this function of probability mass function:

$$f(x;\lambda) = \frac{e^{-\lambda}\lambda^x}{x!} \tag{5}$$

Then we employ POISSON. DIST(1, 1, 1) in Excel. Each chip is removed and examined separately. Therefore, x = 1, as the predicted value is 1 (5000.002), and the final "1" denotes accumulation. The percentage of students that pass is around 0.7358. The ICTM's success probability is higher than that of the LATM, although not quite as high, suggesting that the ICTM's quality control mechanism is better able to identify flaws. As a result, the LATM has an issue in that it cannot reject enough IC chips due to its high pass rate.

2.3 Improving the current product quality inspection method

Table 2. Cumulative Distribution Function for the LATM Inspection Procedure (Photo credit: Original)

x	P(X ≤ x)
0	0.263594

Under circumstances of N = 500, M = 50, and n = 25. The probability of finding a defective IC chip is nearly 0.74 (calculated by 1- 0.263594). However, due to the delayed detection process, several items have made it to market before they completely satisfied the standards. This has resulted in significant consumer dissatisfaction and several complaints. The company suggested a new method of product quality testing to deal with the problem.

Individual Chip Testing Method (ICTM) [1] is a new quality testing strategy presented by the Quality and Reliability Team. In order to complete this operation, 25 of 500 integrated circuit chips will need to be removed and replaced. There is a pressing need to fix any broken chips as soon as they are found. In many ways, this detection method is analogous to sampling with replacement. The results of the hypothesis-based probability calculation are shown in Table 3.

Table 3. Cumulative Distribution Function for the ICTM Inspection Procedure (Photo credit: Original)

x	P(X≤ x)
0	0.717898

3. Customer and Sales

3.1 Sales volume and market demand

Table 4. Figure of ABCtronics sales number (Photo credit: Original)

Year	ABCtronics' sales volume (in millions)	Overall market demand (in millions)	Price per chip (in $)	Economic condition*
2004	2.39	297	0.832	0
2005	3.82	332	0.844	1
2006	3.33	195	0.854	0
2007	2.49	182	1.155	1
2008	1.56	93	1.303	0
2009	0.97	98	1.265	0
2010	1.32	198	1.368	1
2011	1.42	188	1.208	0
2012	1.48	285	1.234	1
2013	1.85	264	1.282	1

Table 4 shows the cumulative sales data for ABCtronics from 2004 to 2013. ABCtronics' sales soared from $2.39 million in 2004 to a remarkable $3.82 million in 2005 because to the superior quality of their offerings and their proactive marketing strategies. However, since then, product quality has deteriorated, and consumer trust has decreased. As we can see in the table, in 2009, the sales volume is at only 0.97 million. However, since 2009, the company's sales volume has increased steadily as a result of continual progress, although it is still on a decreasing trend compared to the first few years. Consequently, it is crucial to enhance product quality and restore customer trust.

Based on the data shown in the Table, Table shows that ABCtronics' sales volume dropped dramatically from 2005, when it peaked at $3.82 million, to the present. The company began a precipitous downturn in 2005, and by 2009, its annual revenues had dropped to $0.97 million. It has rebounded, although overall market demand is still rather low. There was a huge rise in the price of the company's products in 2008 and 2009, and yearly demand in the worldwide market was less than a hundred million; this has had a major effect on the company's revenue thus far. Even though the company has an average annual sales volume of $2.063 million. The company's overall sales volume has dropped dramatically in recent years. This is mostly attributable to improvements in product quality, which were driven by factors including customer demand and market saturation.

3.2 Multiple linear regression model for ABCtronics

Fig. 1 ABCtronics' price per chip in dollars (Photo credit: Original)

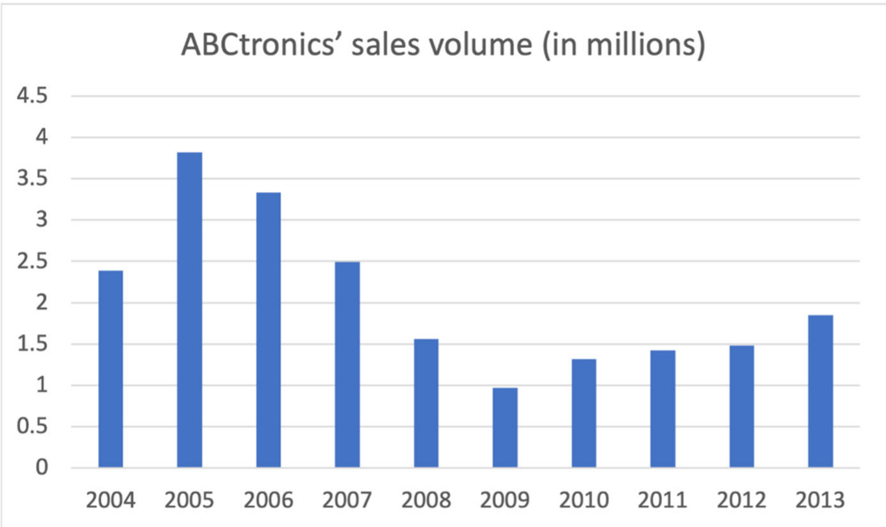

Fig. 2 ABCtronics' sales volume from 2004 to 2013 (Photo credit: Original)

The 2004 pricing of the company's product was $0.832 per unit, while the 2013 price is $1.282 per unit. The product's pricing per unit maintained about $0.8 during the first three years. Subsequently, as a result of 2007's high market demand, demand surpasses supply. As a result, product prices have increased dramatically, from $1.155 to a quick climb in 2010, when the unit price of the company's product reached its greatest value of $1.368, before gradually stabilizing.

Figure 2 shows that ABCtronics' sales volume declined significantly, the highest sale is almost 4 million in 2005.

However, after 2005 the firm has seen a downward trend, and in 2009 it reached its lowest sales volume of less than 1 million. Sales have been severely impacted by the fact that the annual global market demand has been less than 100 million between 2008 and 2009, and the company's product pricing is comparatively costly, representing a large increase compared to earlier years.

Also, although the company's annual revenues have averaged 2 million, less than half of the years have topped that mark. In recent years, the company's entire sales volume has declined significantly. This is because of the quality control problem, as well as client satisfaction, which was influenced by several variables, including consumer desire and market demand.

The sales volume of ABCtronics is the dependent variable, with a value of Y, while the market demand, chip price, and economic climate are the independent factors. Then multiple linear regression should be:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \tag{6}$$

Table 5. Multiple linear regression analysis (Photo credit: Original)

Volume	Coefficient	Standard Error	t	P > $\|t\|$	95% Confidence Interval
Demand	- 0.0052388	0.0025837	-2.03	0.089	0.0010834
Price	- 5.505411	0.8813615	-6.25	0.001	-3.348797
Condition	1.130183	0.3420713	3.3	0.016	1.967201
Cons	8.860711	1.348291	6.57	0.001	12.15986

With a revised R-squared of 0.9976, the aforementioned data show that the model error is minimal, and that there is a clear relationship between the price per chip and ABCtronics' sales volume. The study chart also tells us that for increase in demand, the company's sales volume drops by 0.0052 units, whereas for every increase in unit price, the company's sales volume drops by 5.5054 units. In contrast, a one-unit rise in economic circumstances and disadvantages results in a corresponding one-unit rise in sales volume (1.1302 units and 8.8607 units, respectively).

ABCtronics' sales volume is negatively correlated with both the total market demand and the price per chip, whereas the economic condition is positively correlated with both variables. Furthermore, the p-value calculation findings show that the correlation between the dependent and independent variables is statistically significant [12].

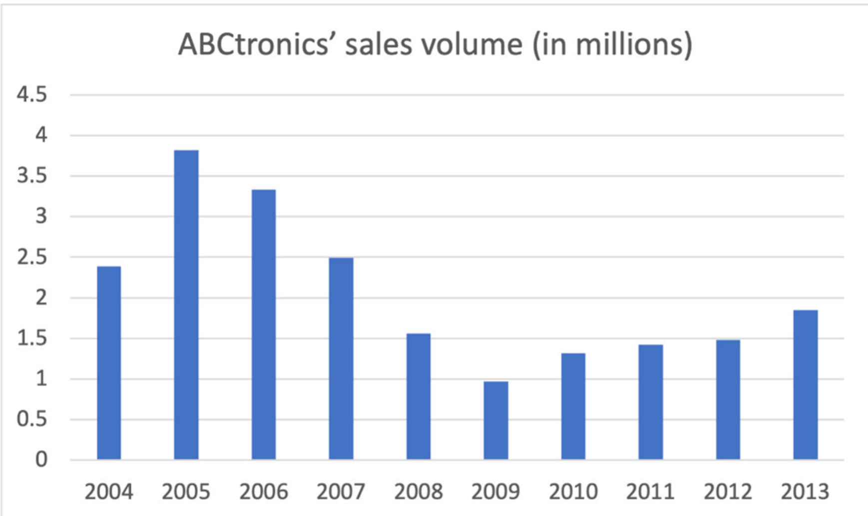

Fig.3 The market demand from 2004 to 2013(Photo credit: Original)

Therefore, we find that most consumers feel that product quality can be improved. An investigation into ways to improve product quality testing finds that the company's inspection procedures and frequency must be changed to reduce testing time and improve testing accuracy. Additionally, we collated general market demand, price per chip, and ABCtronics' sales volume from the duration and constructed a multiple linear regression model to better understand the company's present challenges and offer a more acceptable solution. The results of the system computation indicate a significant relationship between the four factors (market demand, chip price, and ABCtronics' sales volume). ABCtronics' revenue, on the other hand, is positively correlated with general economic health. As a result, this increases the firm's determination to improve product quality.

4. Conclusion

This study aims to give a overview of the whole semiconductor industry by focusing on a virtual but representative firm: ABCtronics. There is no statistical evidence to suggest a connection between satisfied customers and thriving businesses [11]. However, the evidence suggests that there is a connection. The number of tested businesses will need to be investigated further if this is to be confirmed. Though the statistics are statistically insignificant, we nevertheless think this study provides some interesting findings. Satisfaction amongst customers does not seem to be a single quantity, but rather a collection of interrelated partial variables with complex implications for a business's bottom line. This is the only way the effect will be significant enough to change the company's bottom line.

ABCtronics, to remedy this situation, develops a novel quality assurance and control system they call ICTM. Tests are repeated with the same probability by the appropriate divisions of the organization, making this approach comparable to resampling. At the same time as they do the stability testing, they also conduct a comparison of the new approach to the previous technique, LATM. It is therefore concluded that the new method of inspection would work better than the current one. The market will only acknowledge a semiconductor manufacturer if it consistently produces high-quality goods. Using a multivariate regression model, we find that the market demand and chip units pricing seen a negative relation with the sales volume. Good news for the company's bottom line and the economy informs the company's strategic choice to upgrade the quality of its products. In light of the preceding case study, we propose a set of foundational objectives and guidelines to improve both product quality and client contentment for the organization.

Even though this study relies on a hypothetical business and an imaginary incident that occurred in 2016. The lesson from ABCtronics should be learned by the whole semiconductor industry which is IC chips are in low supply due to the high manufacturing cost. It has not yet determined if there will be new substitute or whether there is a more efficient technique to significantly boost output. In order to maintain customer loyalty, the semiconductor firms should break the limitations.

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