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The Economic Value of Statistical Quality Control: Cost Reduction and Competitive Advantage in Manufacturing

Francisco Javier Blanco-Encomienda[1]

Elena Rosillo-Díaz[1]

Juan Francisco Muñoz-Rosas[1]

[1]University of Granada, Granada, Spain

Abstract

In modern manufacturing, quality has transitioned from a technical necessity to a strategic economic asset. This study examines how statistical quality control (SQC) drives measurable financial benefits by reducing defects, minimizing waste, and enhancing process efficiency. Focusing on two fundamental statistical techniques—parameter estimation and hypothesis testing—we demonstrate their pivotal role in identifying process variations and validating improvements. Through practical examples, we illustrate how confidence intervals precisely locate quality deviations, while hypothesis tests confirm the effectiveness of corrective measures, enabling optimal resource allocation. Our analysis quantifies both direct cost savings (e.g., reduced scrap, rework, and warranty claims) and indirect economic gains (e.g., improved customer satisfaction and market positioning). The results show that implementing rigorous SQC protocols delivers rapid return on investment (ROI) and fosters long-term competitive advantage. We argue that integrating statistical methods into production workflows is not merely a quality initiative but a strategic economic decision that enhances sustainable performance. The paper concludes with actionable insights for manufacturers seeking to leverage SQC for financial and operational excellence.

Keywords: statistical quality control, manufacturing economics, cost reduction, process optimization, hypothesis testing, parameter estimation, competitive advantage, ROI

Introduction

The development of a study about quality and control, through statistical methods, is very important for any sector in which a product is generated because it allows reducing the variability of products and, consequently, the reduction of production costs. Through this control possible defects can be detected, taking appropriate measures, allowing the companies to offer a final design of the product adjusted to the standard design, avoiding commercializing products that do not meet with the requirements and needs of the consumer and the model stablished by the designer (Akoglu, Tong, & Koutra, 2015).

There is no doubt that it is essential to offer the highest possible quality products because otherwise it would lead to serious negative consequences, such as the reduction of loyal customers, huge expenses for the losses entailed by the products withdrawal, etc. Furthermore, it is very important to have good statistical tools for the detection of the defects at any point of the production cycle in order to achieve the improvement of the quality of products.

On the other hand, keeping in mind the great scope of the economy and its current situation, it can be seen that nowadays the globalization is such that a small or medium-sized company from anywhere in the world can compete globally. Formerly companies competed on costs advantages and differentiation, but currently as well as keeping this competitive position they must provide at the same time the highest possible quality in their offered products, that is, the control and the improvement of the quality have become an important factor to achieve a firm competitive position.

Moreover, the correct implementation of statistical methods allows obtaining the certification of quality management systems (ISO standards), which can cause a series of benefits in front of the market, because it allows to provide a better image of the products offered by the companies, making it possible to increase the number of customers or sales volume. It can also cause benefits to consumers because it increases their level of satisfaction. Finally, a series of benefits can be generated in the management of the company since it can motivate the workers and encourage them to a continuous improvement in the management of resources (Kafetzopoulos, Psomas, & Gotzamani, 2015; Karipidis, Athanassiadis, Aggelopoulos, & Giompliakis, 2009; Marin & Ruiz-Olalla, 2011). All this shows the importance of treating statistical methods to carry out the quality control in companies, which will allow achieving a better competitive position in relation to the rest.

The purpose of this study is twofold. Firstly, it aims to reflect the importance of statistical methods for quality control in the production process of a company. Secondly, it attempts to demonstrate in practice the usefulness of such methods in problem solving.

The rest of the paper is structured as follows. Section 2 describes how the concept of quality has evolved over the years. In Section 3 the fundamentals of statistical inference are introduced. Section 4 presents the application of statistical inference in the field of quality control in production. Finally, in Section 5 the conclusions of the paper are provided.

Evolution, Concept and Importance of Quality

According to Montgomery (2013) and Mitra (2016), statistical techniques are key tools for the control and improvement of quality, which have to be implemented and be part of the management of the company whose purpose is the quality. So as to achieve the improvement of the quality, one of the administrations employed is the Total Quality Management (TQM), also well-known as Company-Wide Quality Control (CWQC), the Total Quality Assurance (TQA) and six sigma.

Statistical methods for quality control in companies have been gaining importance over the years. Thus, just as the importance of quality has evolved over time, with this concept the same has happened. In addition, these statistical methods for quality control can be adapted to any company and can improve their efficiency and effectiveness (Raja-Sreedharan, Raju, & Srivatsa-Srinivas, 2017). According to Torres (2014), the concept of quality has evolved following four stages:

Quality control, 1940-1959. During this stage the quality is defined as the approval of the specifications, so there are quality control departments dedicated to check these specifications of the products through inspection and control techniques in order to prevent the arrival of erroneous products to consumers, which suppose high costs to companies.

Quality assurance, 1960-1979. At this stage the quality is defined as something suitable for being used. During this period the apex of the companies notes that the quality is important in a worldwide and strongly competitive market. This thought encourages companies to establish a quality management system. In this case, the quality is no longer a high-cost investment and it is transformed into a competitive advantage.

Total quality, 1980-1999. During this period the quality is defined according to customer's satisfaction, known as total quality, which aims to meet with the quality of product, service and management. Therefore, quality is no longer only the responsibility of the quality and production department, but it is just expanded to all company departments.

Business excellence, 2000-present. It is the last period of the evolution of the quality concept. In this stage quality is defined as customer satisfaction and economic efficiency. Customer satisfaction is understood as the consumer's appreciation that their needs, desires or expectations have been reached (Gutiérrez & De la Vara, 2013).

Quality has become one of the most important decision factors for any type of consumer when choosing between competing products, regardless of whether it is an industrial organization, retail store, etc. Thus, the quality improvement is essential to achieve the business success, growth and a strong competitive position, since the quality measures reflect if a good job in terms of customers satisfaction is being done and whether the designs and systems are all compiling the desired requirements (Sallis, 2014).

Although there are different definitions regarding the concept of quality, it will pay attention to the modern definition, which maintains that the quality is inversely proportional to the variability, that is, if the variability decreases the quality of the product will increase, or if the variability increases the quality of the product will decrease.

Emphasizing the modern definition, quality is a necessary element in any company as a fundamental requirement in order to obtain a competitive advantage and achieve an appropriate market share, but companies should not only look for the quality of products. Quality is a relevant requirement to satisfy the demands of customers, hence the companies focus more on the customer than on their products since if a customer gets a defective product the company will lose his loyalty (Torres, 2014).

Furthermore, it is necessary to consider the definition of quality characteristics, which is extracted from Montgomery (2013). These characteristics are the elements that make up products which reflect the idea of quality perceived by the consumer – it can be physical, sensory and time oriented. Therefore, quality engineering corresponds to the productive, administrative and engineering activities that a company uses in order to ensure that the quality characteristics of the product are adapted to the standards.

In turn, these characteristics are evaluated according to the so-called specifications. These are the desired measures of the quality characteristics, which are found in the components and subassemblies that make up the product and the desired values for the quality characteristics in the final product. The desired value for a quality characteristic is known as the target or nominal value, the minimum allowable value for that characteristic is called lower specification limit (LSL) and the maximum allowable value is called upper specification limit (USL). Therefore, the specifications are the result of the design of the product (Kapur & Pecht, 2014).

When a product fails to meet with any of the specifications it is considered as non-conforming, but this does not mean that it is inappropriate. Therefore, it is appropriate to know the term of non-conforming, which is defined according to Besterfield (2009) as a deviation from a quality characteristic in relation to an intended value or state, which is presented with a sufficient severity to make the respective product does not comply with a requirement of a specification. In other words, a product is non-conforming when any of the necessary characteristics to obtain the appropriate level of quality does not reach the necessary value for it, and in addition it is of such importance that it leads to the non-compliance with one of the requirements of any of its specifications.

The definition of defect derives from this last concept, which is similar to the non-conformity, but the defect refers to the fact that the product must satisfy the normal or foreseeable requirements and it is used for the evaluation of the utility of the product (Besterfield, 2009).

According to Gutiérrez and De la Vara (2013), companies are increasingly aware of the positive influence of quality on any aspect of their business because when there is the possibility of a poor quality on any period of the production process errors and mistakes of all kinds (for example, delays, repetitions and surpluses in the productive process, stops at the production cycle, expenses for defective products, conflicts of interest inside the company, dissatisfied customers, etc.) can appear. Thus, an appropriate management of the quality will allow reaching a competitive advantage regarding costs and differentiation (Molina-Azorín, Tarí, Pereira-Moliner, López-Gamero, & Pertusa-Ortega, 2015).

Statistical Inference

Due to the parameters of a process are unknown and in a constant change, it is required to carry out procedures to estimate the parameters of the probability distributions and solve problems of statistical inference or decisions that are related to them.

Statistical inference is understood as the realization of valid assertions about a population or process based on data obtained from a sample. In other words, statistical inference seeks to obtain conclusions or take decisions regarding a sample chosen from the target population, using normally random samples in the analysis.

There are two broad areas of statistical inference: parameter estimation and hypothesis testing. In relation to hypothesis testing, it starts from an assumption that a researcher designs previously to an investigation. This assumption can be true or false and, therefore, it can be approved or rejected.

According to Montgomery (2013), so as to solve the various types of problems of statistical quality control, the processes for testing hypothesis are very relevant. They form the basis for the majority of statistical process control methods.

It should be noted that according to the decision of the researcher when rejecting or not the null hypothesis (affirmation of the value of the population parameter, considered valid for testing) two types of errors can appear:

- Type I error: it is originated in the case in which the researcher rejects a null hypothesis when it is actually true.
- Type II error: it is the inverse of the type I error, that is, when the researcher accepts a null hypothesis that is actually false.

The probability of making a type I error is called α and the probability of making type II error is denoted by β. In terms of quality control, α is known as producer risk, since it reflects the probability that a lot of high quality products is rejected. On the other hand, β is defined as consumer risk, because it corresponds to the probability of accepting a lot of low quality products (Montgomery, 2013, 2017).

Application in the Field of Quality Control in Production

Once the theoretical concepts on the statistical inference in the field of the control and improvement of the quality have been studied, this section presents the application of statistical inference. Specifically, inferences about population proportion given a normal distribution are made.

Confidence Interval

Firstly, a confidence interval for the proportion of defective items has been built, starting from a sample of a total of 10400 items, subdivided into subsamples of 100, of which a total of 1379 are defective items and whose proportion is 0.1326.

Based on the following expression

$$\left[\hat{p} \mp Z_{1-\frac{\alpha}{2}}\sqrt{\frac{\hat{p}(1-\hat{p})}{n}}\right]$$

and considering a 5% level of significance, a lower specification limit (LSL) equal to 0.1261 and an upper specification limit (USL) equal to 0.1391 were obtained.

The results regarding the confidence interval for the proportion of defective items are shown in Table 1.

Table 1: Descriptives

Descriptives		Statistic	Std. Error
Proportion		0.1326	0.0033
95% confidence interval for proportion	Lower bound	0.1261	
	Upper bound	0.1391	
Variance		0.1150	
Std. deviation		0.3391	
Skewness		2.167	0.0240
Kurtosis		2.696	0.0480

4.2. Hypothesis Testing

In order to determine whether the proportion of defective items is less than 14% ($p_0 = 0.14$), a unilateral hypothesis test has been carried out, considering the following null and alternative hypotheses

$$\begin{cases} H_0: & p \geq 0.14 \\ H_1: & p < 0.14 \end{cases}$$

Thus, a left-tailed test is proposed. Using the normal approximation method, the following z test statistic is used

$$Z = \frac{\hat{p} - p_0}{\sqrt{\frac{p_0(1 - p_0)}{n}}}$$

With the sample data and assuming the null hypothesis is true, the value of the statistic was calculated, obtaining a value equal to -2.17. The rejection region was computed using the z-table and the critical value was found to be -1.645 when the level of significance is 5%. As the test statistic is smaller than the critical value the null hypothesis is rejected, so the proportion of defective items is less than 14%.

Using statistical software, the p-value obtained is 0.026. As this value is smaller than the level of significance, the null hypothesis $H_0: \ p \geq 0.14$ is rejected in favor of the alternative hypothesis $H_1: \ p < 0.14$.

Conclusions

The importance of the control and improvement of quality has been growing over the past few decades since it is a requirement that has been increasingly regulated through several national and international standards.

Regarding the production process of a company, managers do not notice problems until the inspection of the final product or until they receive complaints from customers. Thus, the use of statistical methods is crucial for companies in order to improve the quality of the final product and reduce the production costs, hence they are increasingly aware of the importance of having a specialized staff in statistical methods for their application in the production process.

In this paper, a confidence interval for the proportion of defective items has been built. Also, a unilateral hypothesis test has been carried out. This demonstrates the appropriateness of using statistical methods in the field of quality control in production.

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