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# On Issues of Ensuring the Stability of Technological Processes in Improving Product Quality

**Ablazova Kamola Sakhibovna**
Doctor of Philosophy (PhD) in Technical Sciences, k.s.ablazova@gmail.com

**Abstract**
This article discusses the issues of ensuring the stability of technological processes and improving product quality. In product quality control, mathematical statistical methods, in particular the control chart method, are used to determine the stability of processes. In this study, based on the probabilistic statistical approach to constructing a control chart, the control chart method was developed to check data for normality based on the simplest asymmetry and excess symptoms. The possibilities of their practical application are also substantiated.

**Key words:** normal distribution, technological process, stability, control chart, asymmetry, exsess.

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## Introduction

Today, improving the quality of products while ensuring the stability of the technological process is one of the tasks of scientific and practical importance. The development of mathematical models, numerical algorithms and software tools designed to solve practical problems in this wide field of activity is an urgent issue. Such issues are being addressed by scientific and technical personnel in the industrialized countries of the world, including the USA, Japan, China, Germany, Korea, Great Britain, the Russian Federation and other countries, as urgent issues.

American scientists and practitioners such as U. Shewhart, E. Deming, D. Djuran, and others were engaged in research and development on solving problems of product quality management using statistical methods abroad. They achieved high results by using the control chart method in statistical quality assurance. Since these issues are related to the principle of statistical hypothesis testing, the works of scientists such as D. Neumann, E. Pearson, A. Fisher, and A. Wald can be used to construct control charts[4]. It should be noted that the theoretical and practical works of scientists such as A. N. Kolmogorov, Y. K. Belyaev, B. V. Gnedenko, L. N. Bolshev, N. V. Smirnov, D. Himmeloblau, E. Shindovsky, O. Shyurts, R. Shtorm, B. Hansen, and G. Tagutu also made a great contribution to the development of this direction. Currently, the development of the control chart method and the increase in scientific and methodological work in this direction are greatly facilitated by the articles and books of such scientists as B. Woodall, Y. P. Adler, D. Montgomery, H. Y. Mittag, H. Rinne, V. A. Shper, S. F. Zhulinsky, M. Aslam, B. Costa, R. Quinino, D. Wheeler, D. Chambers. Therefore, the number of scientific works on the study of

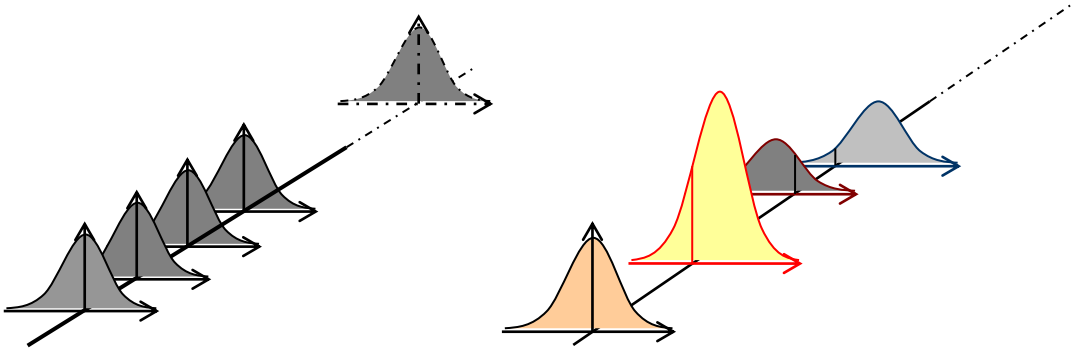
processes using control charts is increasing. The above problems arose in our republic with the entry of joint ventures. To determine the stability of the technological process, these enterprises use ISO standards or standards of some countries.

In developed enterprises in the world, a large number of homogeneous products are produced. Several theoretical and practical models have been created to determine the stability of the technological process, aimed at improving the quality of such products. Currently, the improvement of the control chart model for studying the stability of technological processes, the development of numerical algorithms and software tools are among the urgent issues.

**Methods**

It is known that the stability of technological processes is understood as the property of a technological process that determines the reproducibility of the probability distribution of its parameters over a specified time interval without external intervention.[8]. By the stability of a technological process we understand the property of ensuring the accuracy of product quality parameters over time. [7].

The stability of a technological process is a general indicator of stability. [9] This figure 1.1 depicts the density function of the probability distribution of a parameter of a) stable technological process; b) unstable technological process.



a) b)

**Figure 1.** a) stable technological process; b) unstable technological process.

The quality indicator of products produced in technological operations in technological processes depends on the stability of the technological process. In case a) in Figure 1, the share of quality products is high and the process is predictable, and in case b) the share of quality products is low and the process is unpredictable.

Currently, using the capabilities of science and technology, various software packages have been developed for statistical quality assurance and, in particular, for determining the stability of the technological process: CAQ (computer-aided quality assurance), PPS (production planning and control software package), etc. are examples. However, in real production, there are still losses due to the production of poor-quality products.[6]. The reason is that scientific and technological innovations, including statistical methods, have not been fully implemented in some enterprises.

In technological operations in a technological process, the products produced have different quality characteristics. Therefore, there is variation (dispersion). Historically, there are two principles for reducing this variation. The first is the engineering principle, in which products are divided into quality or poor quality products based on a certain standard. This principle continued from the idea of using parts interchangeably proposed by Eli Whitney in 1793 until 1924, when the American engineer and scientist W. Shewhart developed the principle of using statistical methods in statistical quality assurance. Historically, the first principle did not justify itself, poor-

quality products continued to be produced and costs were high. W. Shewhart created a statistical instrument called control charts (CCs) that reduced variation and costs

## 3. Results

Suppose that the distribution of the numerical characteristic $X$, which determines the quality of the product obtained in technological operations in a technological process, obeys the normal law with parameters $\mu_0 = M(X); \sigma_0^2 = D(X)$: $X \sim N(\mu_0; \sigma_0^2)$. In production, the parameters $\mu_0$ and $\sigma_0^2$ are given as technical standards or are estimated based on initial samples when the technological process is under statistical control [3].

At unit times $t = 1,2,\dots,l$, we take $n$ instantaneous samples $\mathbf{X} = (x_{1t}, x_{2t}, \dots, x_{nt})$ from $X$. Here, $X$ -represents one indicator of the product produced in the technological process, $x_{1t}, x_{2t}, \dots, x_{nt}$ denote the measurement results of $X$ at a specified $t = 1,2,\dots,l$ unit of time.

In technological operations, due to simple (random) or significant reasons, the process may deviate from a stable state (i.e., there will be a deviation from $\mu_0$ and $\sigma_0^2$). In order to correctly assess the state of the technological process using statistical methods, it is necessary to check the state $X \sim N(\mu_0; \sigma_0^2)$ based on $\mathbf{X}, t = \overline{1;l}$ samples[5]. In mathematical statistics, this is done by testing the following hypotheses at the $\propto$ significance level:

$$H_0: P(X < x) = F(x; \mu_0; \sigma_0^2); H_1: P(X < x) \neq F(x; \mu_0; \sigma_0^2).$$

We define the sample mean $\bar{X}_{nt}$, the adjusted sample variance $(S_{nt}^2)$, the sample skewness coefficient $(a_{nt})$, and the sample excess coefficient $(\gamma_{nt})$ based on the instantaneous samples $\mathbf{X}$ taken from $X$ at times $t = 1,2,\dots,l$ as usual: $\bar{X}_{nt} = \frac{1}{n}\sum_{k=1}^{n} X_{kt}$;

$$S_{nt}^2 = \frac{1}{n-1}\sum_{k=1}^{n}(X_{kt} - \bar{X}_{nt})^2;$$

$$a_{nt} = \frac{1}{nS_{nt}^3}\sum_{k=1}^{n}(X_{kt} - \bar{X}_{nt})^3; \gamma_{nt} = \frac{1}{nS_{nt}^4}\sum_{k=1}^{n}(X_{kt} - \bar{X}_{nt})^4.$$

$$S_{nt}^2 > LCL_a = \sqrt[3]{\frac{\bar{\mu}_3^{\,2}}{a_{0,995}^2}} \text{ va } S_{nt}^2 < UCL_\gamma = \sqrt{\frac{\bar{\mu}_4}{\gamma_{0.005}}} \qquad (1)$$

Bunda $\bar{\mu}_3 = \frac{1}{m}\sum_{t=1}^{m}\mu_{3t}, \mu_{3t} = \frac{1}{n}\sum_{k=1}^{n}(X_{kt} - \bar{X}_{nt})^3; \bar{\mu}_4 = \frac{1}{m}\sum_{t=1}^{m}\mu_{4t},$

$$\mu_{4t} = \frac{1}{n}\sum_{k=1}^{n}(X_{kt} - \bar{X}_{nt})^4.$$

Let $a_\propto$ and $\gamma_\propto$ be the quantiles of the distributions $a_n$ and $\gamma_n$, respectively, at the $\propto$ value level. Let $\chi^2$- denote the $Ch\{*|n-1\}$ distribution with $n-1$ degrees of freedom.[10].

### 3.1. The mathematical model of technological process stability "Asymmetry-excess":

If the following relation holds for the samples $(X_{1t}, X_{2t}, \dots, X_{nt})$ at a given unit time $t = \overline{1;l}$, the technological process is stable:

$$S_{nt}^2 > LCL_a = \sqrt[3]{\frac{\bar{\mu}_3^{\,2}}{a_{0,995}^2}} \text{ va } S_{nt}^2 < UCL_\gamma = \sqrt{\frac{\bar{\mu}_4}{\gamma_{0.005}}} \quad (1)$$

Here $\overline{\mu}_3 = \frac{1}{m}\sum_{t=1}^{m}\mu_{3t}$, $\mu_{3t} = \frac{1}{n}\sum_{k=1}^{n}(X_{kt} - \bar{X}_{nt})^3$; $\bar{\mu}_4 = \frac{1}{m}\sum_{t=1}^{m}\mu_{4t}$,

$$\mu_{4t} = \frac{1}{n}\sum_{k=1}^{n}(X_{kt} - \bar{X}_{nt})^4.$$

**$a$- control chart boundary definition:**

1) we generate instant samples at unit times $t = \overline{1;m}$ of the initial phase of production and determine $\bar{X}_{nt}$;

2) we find $\mu_{3t}$ at moments $t = \overline{1;m}$;

3) we determine the arithmetic mean $\overline{\mu}_3$ of the found $\mu_{3t}$ values and obtain $\bar{\mu}_3^{\,2}$. We divide the result by the quantile $a_{0,995}^2$, take the cube root, and determine $LCL_a$ and draw the lower limit of the control chart in the Cartesian coordinate system;

**$\gamma$ – determination of the CC limit:**

4) Based on the data in 1), we determine $\mu_{4t}$ at moments $t = \overline{1;m}$;

5) The arithmetic mean of the found values is found to be $\bar{\mu}_4$ and the quantile $\gamma_{0.005}$ is taken as the square root, and we determine $UCL_\gamma$ and draw the upper limit of the control chart in the Cartesian coordinate system;

**3.2. Determining the values of $S_{nt}^2$, which determine the stability of the technological process:**

6) Now we take instantaneous samples from the production at $t = \overline{1;l}$ units of time and determine $\bar{X}_{nt}$;

7) Based on the samples at $t = \overline{1;l}$ units of time, we find the values of $S_{nt}^2$ and determine their values in the Cartesian coordinate system;

**Analyzing the stability of the technological process:**

8) If the inequality $LCL_a < S_{nt}^2 < UCL_\gamma$ is valid in the resulting $a - \gamma$ double control chart diagram at $t = \overline{1;l}$ units of time, then the technological process is stable, otherwise it is unstable.

Below is a sample diagram of the mathematical model (1). In this case, the analysis of the stability of the technological process is presented in accordance with the figure.

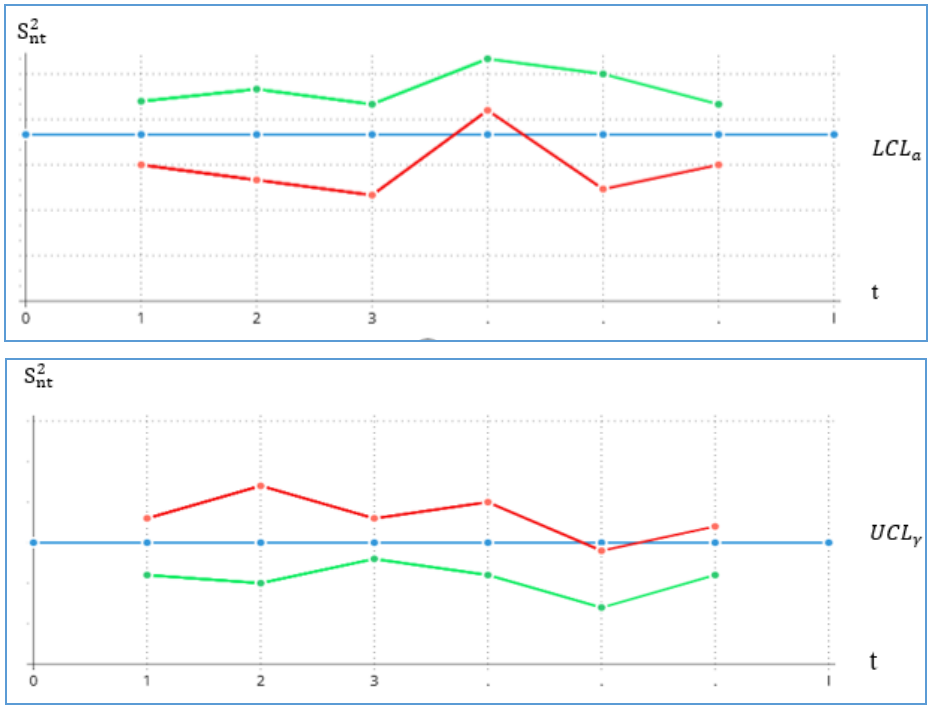



**Figure 2.** $a - \gamma$ **control chart mathematical model diagram.**

In the figure, the points satisfying the above inequality (1) are marked with a blue dashed line, and those that do not satisfy it are marked with a red dashed line. The green line indicates a stable, and the red line indicates an unstable technological process. The upper figure indicates asymmetry, and the lower one indicates an excess state.

**3.3. (1) the mathematical model is built based on theorems 1 and 2 below. In this case, the controlled quantity of the control card is** $g(X_t) = S^2_{nt}$.

**Theorem1**[1]. $\propto = 0{,}01$ and $H_0: P(X < x) = F(x; \mu_0; \sigma_0^2)$ when the hypothesis is valid, the lower control limit of the $a$-CC is equal to $LCL = \sqrt[3]{\frac{\bar{\mu}_3{}^2}{a^2_{0,995}}}$. And the $a$ -control chart power function is equal to $G_a(\sigma_t) = P(S^2_{nt} \le LCL) = Ch\left\{\frac{n-1}{\sigma_t^2}\sqrt[3]{\frac{\bar{\mu}_3{}^2}{a^2_{0,995}}}\,|n-1\right\}$

**Theorem2**[1].

$\propto = 0{,}01$ and the hypothesis $H_0$ is valid, the control limits of the $\gamma$ -control chart are $LCL = \sqrt{\frac{\bar{\mu}_4}{\gamma_{0.995}}}$; $UCL = \sqrt{\frac{\bar{\mu}_4}{\gamma_{0.005}}}$ . The power function of the $\gamma$ -control chart is $G_\gamma(\sigma_t) = P(S^2_{nt} \ge UCL) = 1 - Ch\left\{\frac{n-1}{\sigma_t^2}\sqrt{\frac{\bar{\mu}_4}{\gamma_{0.005}}}\,|n-1\right\}$

## 4. Conclusions

The scientific results obtained in the article are based on the fact that the data obtained for the study of problems in the welding shop of UZ Auto Motors JSC during the operation of controlling the gap between two panels and in the painting shop during the priming of the car body were checked for normality (i.e., determining the stability of the technological process) using $a - \gamma$ control chart models, and positive results were obtained. In [2], mathematical models were built based on control charts found on the basis of Kolmogorov or Kolmogorov-Smirnov type statistics. These control chart models ensure the stability of the technological process.

The mathematical models developed are of theoretical and practical importance. They can be used to ensure the stability of the technological process. This, in turn, will allow improving the quality of products produced during technological operations in the technological process.

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