QUALIMETRIC METHOD OF ASSESSING RISKS OF LOW QUALITY PRODUCTS

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Risk assessment is an integral part of an enterprise's quality management system. The risk of low quality products is the most significant risk, as it is directly related to the concept of enterprise competitiveness. The paper analyzes the scientific papers related to the assessment of the quality of products, processes and services, their disadvantages, possible limits of application. It is proposed to use mathematical dependences to obtain estimates of product quality indicators on a dimensionless scale. Knowing the density function of random variables of product quality indicators and knowing the mathematical dependence of their estimates on a dimensionless scale, it is proposed to obtain the density function of estimates. Knowing the function of the density of estimates of quality indicators, it is proposed to find the probabilities of risks of the assessment of quality indicators in any given interval on a dimensionless scale. A method for assessing the risks of low quality products has been developed

KEYWORDS

qualimetry; risk assessment; risk of low quality; summarizing indicator; multicriteria quality assessment; dimensionless scale

1. INTRODUCTION

One of the principles of development and implementation of the international standard [ISO 9001:2015] is the principle of risk assessment, which requires companies and organizations to develop methods for analyzing, forecasting and risk management. The requirements of this standard indicate that the organization should: "identify and assess risks and opportunities that may affect the quality management system and the results of the work of organization; create a plan to respond to risks and opportunities; make decisions based on the results of risk assessment."

At the manufacturing enterprise, the sources of risk are associated not only with the main production activity, but also with all stages of the product life cycle, related activities, actions of employees, stakeholders, and others. To successfully manage risks you need to be able to analyze and forecast them, which will increase the efficiency of management processes. The purpose of the risk assessment process is to determine the magnitude and probability of adverse effects.

Today there are no universal methods of risk assessment for different enterprises or processes, so the enterprise must independently determine the method of analysis, in terms of its feasibility, depending on: the complexity and nature of the system under study; methods of control; properties that provide traceability, repeatability and controllability. The way out of this situation is to develop a standard methodology for risk assessment for groups of processes, among which are important processes of the production cycle [Panda 2014, 2018a,b, 2019; Valicek 2016 & 2017, Macala 2009 & 2017, Pandova 2018, Monkova 2013, Dyadyura 2017, Pollak 2020a,b, Olejarova 2017, Rimar 2016, Straka 2018a,b].

The aim of the paper is to develop a methodology for assessing the production risks of manufacturing low quality products. This method must be universal so that it can be used in different enterprises for the manufacture of various products [Mrkvica 2012, Cacko 2014].

2. MATERIALS AND METHODS

Traditionally, risk assessments are performed in various ways, based, for example, on a combination of observations, trends and other information. We can identify the most common methods of risk assessment:

- Basic auxiliary methods of risk management (flowcharts, control charts, etc.);
- Failure Mode Effects Analysis (FMEA);
- Failure Mode, Effects and Criticality Analysis (FMECA);
- Fault Tree Analysis (FTA);
- Hazard Analysis and Critical Control Points (HACCP);
- Hazard Operability Analysis (HAZOP);
- Preliminary Hazard Analysis (PHA);
- Risk ranking and filtering;
- Appropriate statistical methods.

Currently, there are methods for calculating risks, which are conveniently divided into two groups:

qualitative methods allow to obtain averaged generalized information about the risk of harm to product groups or the value of risk for a particular type of product;

quantitative methods: statistical, which allow to obtain averaged over a homogeneous group of products or populations information about the risk (safety) of harm;

estimated (individual), allowing to obtain the value of risk for a particular type of product.

Conceptual aspects of risk management are highlighted in the experience of many scientists. As P. Tworek notes in her publication, in accordance with the new priorities caused by changes in society, there is a constant change of management structures, and thus traditional models of public administration become ineffective [Tworek 2016].

M. Sartor emphasizes in his research that in most developed countries of the world risk management is given considerable attention both in the private sector of the economy and in public administration at all levels. Scientists around the world are working to create effective risk management tools [Sartor 2020].

The results of research by scientists from Australia, New Zealand, Japan and a number of other countries are the development of international standards ISO 31000: 2009 "Risk Management. Principles and Guidelines" and ISO 73: 2009 Risk management. Dictionary". They have become effective tools used by private, state and municipal organizations in developed countries to develop, implement and continuously improve the risk management system as a mandatory component of management systems in general [Hogarth 2018].

The publication of N. Silva and M. Arrfelt studies the theoretical and practical issues of risk management in enterprises, including the functions and main stages of implementation of risk management [Silva 2021, Arrfelt 2018].

V. Zaloga analyzing the international standard of risk management ISO 31000: 2009, considers the relationship between the principles, system and process of risk management and changes in the terminology [Zaloga 2019]. A. Panda [Panda 2019] in his works underpins the basic principles and approaches on improving the risk management system in construction, namely the introduction of consulting engineers and advanced training of key personnel of construction companies.

Consider the various definitions of risk given by domestic and foreign authors:

1. Risk – a potential, numerically measurable possibility of loss. The concept of risk is characterized by uncertainty associated with the possibility of adverse situations and consequences during the project realization [Goel 2019].
2. Risk – the probability of losses, shortfalls of planned income, profit [Nepomnyashchyy 2017].
3. Risk is the uncertainty of our financial results in the future [Lagunova 2018].
4. G. Linton defines risk as the degree of uncertainty in obtaining future net income [Linton 2019].
6. Risk – the probability of loss of values (financial, material commodity resources) as a result of the activity, if the situation and conditions of the activity will change in a direction different from the risk provided by plans and calculations [Zaloga 2020].
7. Risk - the impact of uncertainty on the goal [ISO 9001:2015].

The role of risk in the enterprise is very large, experts understand the importance of risk management, but in practice there are many controversial issues due to the lack of a holistic theory of risk management and the ambiguity of the use of different methods of their assessment.

An international standard has been developed for risk assessment [ISO 31000:2018]. This document provides recommendations for managing the risks faced by organizations in the process of ensuring the life cycle of products and services. The procedure for applying these recommendations can be adapted to any organization. This standard contains a general approach to risk management and is not highly specialized or industry-specific. It can be applied throughout the life cycle of the organization and to any activity, including decision-making at all levels.

To develop the standard [ISO 31000:2018], a standard [IEC 31010:2019] was developed, which provides recommendations for the selection and application of systematic methods of general risk assessment. Standard [IEC 31010:2019] is of a recommendatory nature, so it can serve as a guide for different types of management systems. Organizations that develop quality management systems in accordance with [ISO 9001:2015] should develop their documented procedures for risk assessment and management.

There are also qualimetric assesssment methods that can be used as a mathematical apparatus for risk assessment. In works [Trishch 2006a,b, 2020] to obtain estimates of different quality indicators on a dimensionless scale there was used the dependence, which had a double exponential form. The authors [Cherniak 2020, Trishch 2016, Ginevicius 2015] used the type of dependencies to keep the assessment of quality indicators on a dimensionless scale, using ordinal statistics.

Scientists, in their works [Ghoddousi 2017] to obtain estimates of quality indicators on a dimensionless scale use the method of SAW (Simple Additive weighting), the meaning of which is in the application of weighting factors for individual quality indicators.

The TOPSIS method is also often used - a method of multi-criteria evaluation, which uses a reference value of quality [Niu 2020, Gitinavard 2017]. The TOPSIS method is also used to obtain a comprehensive assessment of quality indicators [Bruno 2018, Krenicky 2020, Masdari 2021].

Methods are often used to evaluate processes in social research: PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) [Thakkar 2021b]; MOORA (Multi-Objective Optimization Method by Ratio Analysis) [Thakkar 2021a]; WASPAS (Weighted Aggregated Sum Product Assessmentset) of various social objects [Senapati 2021].

Thus, as a result of the analysis of scientific research, it can be concluded that qualimetry methods are used to assess the quality of qualimetry objects of different nature and in different fields and areas of research, so it is proposed to use them to develop methods for assessing the risk of low quality products.

3. METHODS FOR ESTIMATING THE PROBABILITY OF LOW QUALITY PRODUCTS

To achieve this goal, it is necessary to solve a number of scientific and applied problems:

Since the products are characterized not by one but by many quality indicators and they can have different scales and ranges of measurement, it is necessary to determine the function of the dependence of the measured quality indicators with their estimates on a dimensionless scale. That is, you need to determine the functionally dependent statistics.

Let's define the law of distribution of functionally dependent statistics as random variables. That is, it is necessary to know the density function of functionally dependent quantities on a dimensionless scale.

Knowing the law of distribution of random variables on a dimensionless scale, it is necessary to determine the probabilities of getting a random variable in a given evaluation interval.

To solve the problems, we will use the mathematical apparatus of qualimetry as a science of quantitative quality assessment. In qualimetry, when assessing the quality of objects, an important place is taken by the type of relationship between the measured quality indicators and their evaluation on a dimensionless scale, as quality indicators are not always evenly distributed and do not always have a linear mathematical relationship with their evaluation. To manage the quality of the object there are often used statistical methods of evaluation and management, where the basic information is not to know the law of distribution of quality in its units, but to know the law of distribution of their estimates on a dimensionless scale. Therefore, in the framework of this paper, we will investigate the patterns of distribution of quality indicators on a dimensionless scale.

The technological process is a complex system, the state of which is to be assessed, analyzed, forecast and, if necessary, adjusted to ensure product quality. Under the object of qualimetry, in this paper, we will consider the result of the technological process - obtaining a product of a given quality.

As a result of the influence of random factors on the quality indicators of each product, we obtain results that change with each product. In quality management in such conditions, the methods of mathematical statistics are used mainly for statistical analysis. The purpose of statistical analysis is to study the properties of a random variable. The effectiveness of the application of mathematical statistics for quality assessment depends on the amount of statistical information. Statistical information is contained in the knowledge of the law of distribution of quality indicators, as a random variable and the presence of a significant number of sample values.

Let the random value of scattering of any quality indicator of the object of qualimetry X be subject to the normal distribution law and be related to the random value Y by the dependence Y= $F(x)$:

$$F(x) = \begin{cases} 0 & x_i \le x_{i\,min} \\ \left[\frac{x_i - x_{i\,min}}{x_{i\,max} - x_{i\,min}}\right]^k & x_{i\,min} < x_i > x_{i\,max}, \\ 1 & x_i \ge x_{i\,max} \end{cases} \tag{1}$$

where x_i – the actual value of the quality indicator; $x_{i\,min}$ – the minimum allowable value of the quality indicator; $x_{i\,max}$ – the maximum allowable value of the quality indicator; k - the exponent (form parameter);

Let's find the probability density of a random variable Y. As is known, the equation for finding the probability density function q (y) of a random variable Y has the form:

$$q(y) = f(\psi(y))|\psi'(y)|$$

where $f(x)$ - the probability density of a random variable X; $\psi(y)$ – is an inverse function to $y = F(x)$ and which, in the range of possible values of a random variable X, has a derivative.

So, we find the function inverse to:

$$y = \left[\frac{x_i - x_{i\,min}}{x_{i\,max} - x_{i\,min}}\right]^k, \ x_{i\,min} < x_i > x_{i\,max} \ .$$

As a result of algebraic transformations we have:

$$x = \psi(y) = y^{\frac{1}{k}}(x_{max} - x_{min}) + x_{min},.$$

Let's find the derivative of the function $x = x(y)$:

$$x'_y = (\psi(y))' = \frac{1}{k} y^{\frac{1}{k}-1}(x_{max} - x_{min}),$$

$$x'_y = \frac{(x_{max} - x_{min})}{k}\left(\frac{1}{y^{1-\frac{1}{k}}}\right).$$

If the random scattering value of the quality index of any process X is subject to the normal distribution law with the density function

$$f(x) = \frac{1}{\sigma_x\sqrt{2\pi}} e^{-\frac{(x-m_x)^2}{2\sigma_x^2}}, \tag{2}$$

then the probability density function q (y) of a random variable y will look like this:

$$q(y) = \left|\frac{x_{max} - x_{min}}{k y^{1-\frac{1}{k}}}\right| \frac{1}{\sqrt{2\pi}\sigma_x} e^{-\frac{\left[y^{\frac{1}{k}}(x_{max} - x_{min}) + x_{min} - m_x\right]^2}{2\sigma_x^2}}, \tag{3}$$

where mx – mathematical expectation of the values of the quality indicator;

σx – is the standard deviation of the values of the quality indicator.

The methodology for assessing the risks of low quality products consists of the following steps:

To determine the quality of products (products);

To determine the permissible limits of their quality indicators. Permissible limits can be determined by relevant regulations.

To determine $x_{i\,min}$ – the minimum allowable value of the quality indicator and and $x_{i\,max}$ – the maximum allowable value of the quality indicator;

To measure the true quality of the product x_i;

According to formula (1) to determine the value of the quality indicator Y on a dimensionless scale;

Knowing the density function of the distribution law of a random variable X, we find the density function of a random variable Y on a dimensionless scale. If the density function corresponds to the normal distribution law (2), then the probability density function q (y) of the random variable y will look like (3).

Knowing the density function of a random variable of a dimensionless quality indicator, we determine the probabilities of a random variable entering a given interval on a dimensionless scale by formula (4).

Therefore, knowing the law of distribution of individual indicators of product quality and knowing the dependence of their assessments on a dimensionless scale, it is possible to solve practical problems to determine the probability of assessments of quality indicators in a given assessment interval, i.e. to determine the risk of undesirable quality.

To test the method, it is proposed to use modeling of the process of scattering of product quality indicators as random variables, using the Monte Carlo method. 500 values of random variables were obtained according to the law of normal distribution with density function (2) and parameters: mx =2,5; σx=0,8.

4. RESULTS

Applying the method of assessing the risks of low quality products, the following results were obtained (Fig. 1, Fig. 2, Fig. 3, Fig. 4). Here is (Fig. 1) a graph of the probability density function q (y) of a random variable y, in the case when the parameters have the following values: mx =2,5; σx=0,8, and the parameter of the form k changes.

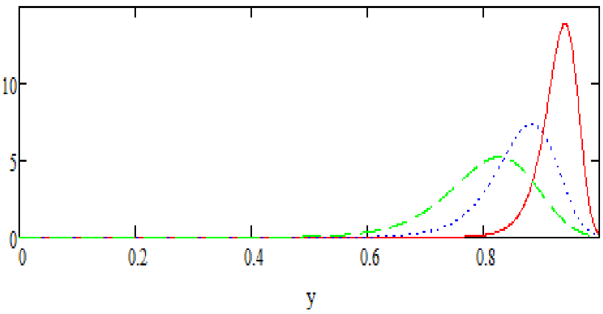

Figure 1. Graph of the probability density function of a random variable Y for shape parameters: k = 0,1; 0,2; 0,3.

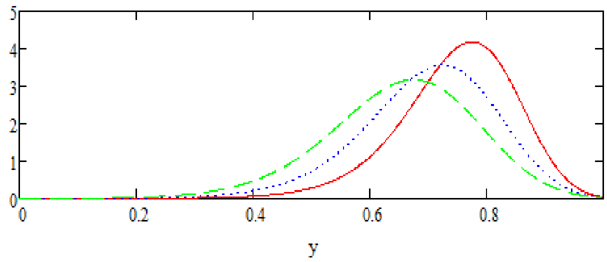

Figure 2. Graph of the probability density function of a random variable Y for shape parameters k = 0,4; 0,5; 0,6.

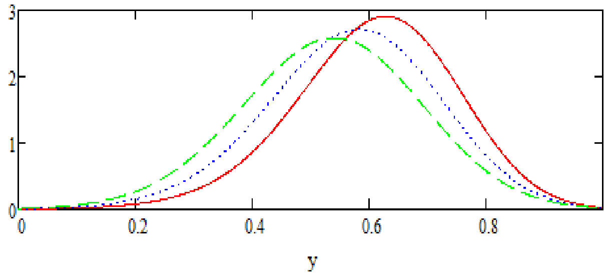

Figure 3. Graph of the probability density function of a random variable Y for shape parameters: k = 0,7; 0,8; 0,9.

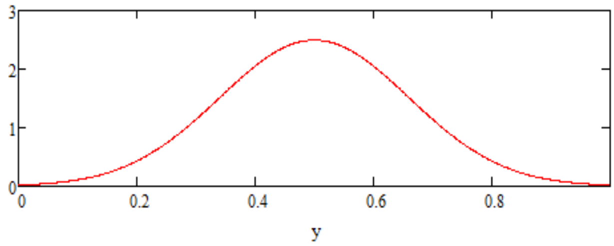

Figure 4. Graph of the probability density function of a random variable Y at a shape parameter: k=1.

If the probability density function for a random variable Y is known, then a number of practical problems can be solved, in particular, to find the probability that the value of a random variable Y falls within a certain range (c; d):

$$P(c < y < d) = \int_c^d q(y)dy = F(d) - F(c),$$

where $q(y)$ - distribution function of a random variable Y.

Let's consider some practical task - It's find the probability that the values of a random variable Y fall into the interval (c; d). To do this, it is necessary to calculate the integral:

$$P(c < y < d) = \int_c^d q(y)dy. \qquad (4)$$

As a result of the calculations we obtained the results presented in Table 1.

Table 1. The probability of hitting the value of a random variable Y in the interval (c; d), provided that k varies from 0.1 to 1 at 0.1 intervals.

Interval c - d											
k	0-0,1	0,1–0,2	0,2–0,3	0,3-0,4	0,4-0,5	0,5-0,6	0,6-0,7	0,7-0,8	0,8-0,9	0,9-1	0-1
Probability $P(c < y < d)$											
0,1	1,9x10-12	1,9x10-9	1,09x10-7	2x10-6	1,7x10-5	1x10-4	6x10-4	5,5x10--3	0,165	0,827	1
0,2	1,9x10-7	5,9x10-6	4x10-5	1,7x10-4	5,9x10-4	2,5x10-3	0,015	0,122	0,573	0,285	1
0,3	8,8x10-6	8,4x10-5	3,2x10-4	1,03x10-3	3,8x10-3	0,017	0,087	0,328	0,46	0,1	1
0,4	6,2x10-5	3,4x10-4	1,1x10-3	4x10-3	0,015	0,062	0,203	0,388	0,279	0,046	1
0,5	2,09x10-4	9,2x10-4	3,2x10-3	0,012	0,042	0,132	0,284	0,334	0,164	0,025	1
0,6	5,04x10-4	2,1x10-3	7,7x10-3	0,027	0,085	0,2	0,303	0,255	0,101	0,016	1
0,7	1,03x10-3	4,3x10-3	0,016	0,053	0,136	0,244	0,28	0,186	0,066	0,011	1
0,8	1,9x10-3	8,3x10-3	0,03	0,087	0,182	0,26	0,24	0,136	0,045	8,4x10-3	1
0,9	3,2x10-3	0,015	0,05	0,124	0,215	0,254	0,198	0,1	0,032	6,6x10-3	1
1	5,3x10-3	0,024	0,075	0,16	0,234	0,234	0,16	0,075	0,024	5,3x10-3	1

The table shows that, knowing the parameter of the form k, we have the probability of getting a dimensionless value of the evaluation of the quality indicator in any interval on the dimensionless scale. For example, using table (1) we find the probability that the estimate of product quality will be less than 0.8 at k = 0.3. Therefore, P (0 <y <0.8) = 0.44. Thus, you can find the probability of getting the value of the dimensionless evaluation of the quality indicator in any interval on the dimensionless scale.

5. CONCLUSIONS

The result of this paper is a method for determining the probability of low quality products. To develop a methodology:

1. Substantiated the function of dependence of the measured quality indicators with their estimates on a dimensionless scale, which allowed obtaining functionally dependent statistics.
2. Determined the density functions (Fig. 1 – 4) of functionally dependent random variables of quality indicators, provided that the quality indicators are subject to the normal distribution law.
3. Performed testing of the method and determined the probabilities of random variables in a given evaluation interval (Table 1).

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