

Generalized indicator of the quality of qualimetry objects of various nature

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Abstract. The production of high-quality products stimulates Ukrainian manufacturers to enter the European and international markets, which at the same time stimulates domestic manufacturers to produce competitive products on a par with high-quality foreign alternative products. The promotion of competitive high-quality products to the European and world markets will make it possible to strengthen the national currency, which will actively contribute to the improvement of the economy of Ukraine, will create appropriate conditions for the development of entrepreneurial activity, fair competition, and improvement of the level of well-being of the population. The only approach to evaluating the quality of products is designed to quickly monitor indicators throughout the entire cycle of its production. In order to most economically and quickly achieve the goal in the field of qualimetry without violating the current restrictions, there is a need to optimize the requirements for product quality indicators. There are a number of methods that have their own advantages and disadvantages for each object of quality measurement. The purpose of the work is to analyze the mechanisms of quality metrics and to combine their advantages into a joint assessment model. The research was conducted using the methods of analysis, synthesis, comparison, generalization and induction. The article presents the methodology for determining the generalized quality indicator of quality measurement objects of various nature, including: products, technological processes, systems, or anything that requires a step-by-step assessment. Based on the analysis of existing non-linear relationships between the measured quality indicator and its assessment on a dimensionless scale, a method based on the use of generalized quality indicators is proposed. The application of the proposed method will provide a high-precision assessment of a wide range of objects with the fixation of changes over time

Keywords: technological process, shape parameter, production cycle, use of statistical information, mathematical dependence

INTRODUCTION

Production of high-quality products enables Ukrainian manufacturers to enter European and international markets, which in turn stimulates national manufacturers to produce competitive products alongside high-quality foreign counterparts. Promotion of competitive high-quality products to European and world markets will strengthen the national currency, which will contribute to the growth of the economy of Ukraine, will create favorable conditions for the development of entrepreneurial activity, fair competition, improvement of life and health of the population.

Leaders of the world economy have proven that in order to achieve high results in the field of quality, a

constant process of their evaluation, research and management is necessary. Qualimetry objects have a different nature, and it is not always possible to measure their quality indicators, so they have to be evaluated by various existing methods [1]. Objects of various nature can include products, services, products, processes, systems or anything that is subject to evaluation for the purpose of quality management.

To maintain a high level of product quality, there should be a single approach to evaluation that will be applied at all stages of the product production cycle. A typical product production cycle includes the stages of its creation from raw materials to finished products. Each

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of these stages has its own quality indicators, established in regulatory documents of different levels and periods of publication with different units of measurement.

It is not always advisable to increase all indicators of product quality. Products must be competitive, that is, the ratio of quality and price must meet the requirements of consumers. Therefore, it is necessary to optimize the requirements for product quality indicators. Optimization consists in determining and establishing such values of quality indicators, at which the set goal in the field of quality is most economically and quickly achieved without violating existing restrictions, that is, laws or regulatory documents.

As an optimization method, a method based on the use of generalized quality indicators is proposed. With this approach, a number of advantages are achieved, which include increasing the methodological reliability of quality assessment, reducing the list of controlled indicators, the possibility of unifying diagnostics, etc. However, there are certain difficulties associated with the definition of a generalized quality indicator.

A number of scientific works by domestic scientists are devoted to the problems of assessing the quality of quality measurement objects. B.I. Stadnyk [2] in his works considered the main problems of the development of qualimetry, namely, the use in the theory and practice of qualimetry of the conceptual concept "qualimetric measurements" as one of the types of measurements, which in turn made it possible to combine the methodology of qualimetry and metrology and significantly to expand the capabilities of qualimetry regarding the reliability and accuracy of the obtained product quality assessments. R.I. Baitsar [3; 4] proposed a method of harmonizing the quality management system of an industrial enterprise according to the new ISO 9001:2015 standard, this method makes it possible to more efficiently organize the passage of information flows, decentralize responsibility for product quality, and improve interaction with the customer. In the works of P.G. Stolyarchuk [5], the essence of methods and means of determining product quality indicators is revealed, the peculiarities of classification and application of quality indicators for various types of products are indicated, and the basic provisions of qualimetry are also outlined. Considerable attention is paid to the applied aspects of determining the quality indicators of objects of various nature and their application. M.I. Novytskyi [6] described a systematic approach to product quality management and considered the organizational and methodological foundations of product certification and metrological activity. H.G. Azgaldov [7] is generally the initiator of the creation of the scientific discipline of qualimetry, which studies the methodology and problems of quantitative assessment of the quality of objects of any nature: objects or processes, products of labor or products of nature that have a material or spiritual nature.

In the scientific works of foreign scientists: C. Fletcher [8], L.C. Struckenbruck [9], P.G. Tzamalīs, D.B. Panagiotakos, E.H. Drosinos [10], M.F. Rebelo, G. Santos, R. Silva [11], topical issues of quality assessment of quality metrics, namely how to manage quality and projects.

The analysis of the scientific literature of domestic and foreign authors showed that the existing methods are mainly aimed at evaluating the quality of products and consist in the averaging of single quality indicators when determining a complex or integral quality indicator [12]. This approach should not be used to assess the quality of such quality metrics as processes or systems.

The purpose of the article is to study the method of determining the generalized indicator of the quality of quality measurement objects of various nature, including products, technological processes, systems, or anything that is subject to evaluation. Therefore, the task was set to develop and scientifically substantiate new quality assessment methods that would take into account the heterogeneity of indicators of objects of different nature.

RESEARCHING THE MECHANISMS OF QUALITY METRICS AND COMBINING THEIR ADVANTAGES INTO A COMMON ASSESSMENT MODEL

In qualimetry, when assessing the quality of objects of various nature, an important place is occupied by the type of dependence between the measured quality indicator and its assessment on a dimensionless scale. After all, quality indicators are not always evenly distributed and do not always have a linear mathematical relationship with their assessment. The development of objective mathematical dependencies is a time-consuming and urgent task that requires a deep and comprehensive study of the object, which can be explained by the fact that in most existing methods of quality assessment fairly approximate formulas are used, which poorly reflect the main ideological principles of the quality assessment process [12].

To ensure and maintain a high level of product quality, there should be a single approach to evaluation, that is, there should be a single metric that will be used at all stages of the product life cycle. One of these approaches is to consider the production of products at all stages of the life cycle as a single technological system aimed at obtaining high-quality products. A typical production life cycle includes the stages of its creation from raw materials to finished products. Each of these stages has its own quality indicators, established in regulatory documents of different levels and periods of publication with different units of measurement.

A technological system is understood as a set of interconnected technological processes, equipment, equipment, devices for measurement, analysis and control, as well as a management process intended for the manufacture of products. The basis of such a technological system is information integration of all stages

of product creation. It involves the use of information models that describe products and their production technologies, which allows having the same methods of managing processes. In such conditions, some quality indicators may be underestimated, which may lead to a decrease in the quality of finished products or an increase in the price of subsequent operations, while others may be overestimated, which will increase their cost [13].

For the effective use of information models operating within the technological system, it is desirable to have a unified system for evaluating the quality of products and technological processes at all stages of the life cycle of its creation. This will improve the efficiency of using statistical information.

To optimize quality indicators, it is necessary to carry out a number of works in order to obtain additional information or reduce its uncertainty. There is always uncertainty, so there is a problem of finding a compromise, for example, between the cost and the quality of the product [14].

To optimize quality indicators, it is proposed to use a method based on the use of generalized quality indicators. With this approach, a number of advantages are achieved, which include increasing the methodological reliability of quality assessment, reducing the list of controlled indicators, the possibility of unifying diagnostics, etc. However, there are certain difficulties associated with the definition of a generalized quality indicator.

Determining the generalized indicator of product quality is related to the creation of a single assessment that quantifies quality through its indicators. The task can be solved by introducing a single artificial metric for all indicators of product quality and processes. The set of values of each quality indicator needs to be matched with a certain standard analogue, with a single quality rating scale from zero to one. This scale should be the same for all indicator values. The construction of this scale is related to the distribution of quality indicators as random variables. This task can be solved by combining single evaluations of product quality indicators with a generalized quality indicator.

Any quantitative assessment of quality defined by a single number is a point estimate and is subject to error. Therefore, the task was set - in addition to the point generalized assessment of product quality, to find a generalized interval assessment of quality, which allows optimizing quality indicators at all stages of the product life cycle and creating a unified system of assessing the quality of technological systems. The definition of a generalized indicator of product quality is related to the creation of a single assessment that quantifies quality through its indicators. The task can be solved by introducing a single, artificial metric for all quality indicators of products and processes.

To solve the set goal, an analysis of the existing non-linear dependencies between the measured quality indicator and its assessment on a dimensionless

scale was carried out and, taking into account their shortcomings, a new type of dependencies is proposed:

$$f(q) = \frac{1}{1+ab^{-kq}}, \quad (1)$$

where a, b – coefficients of process quality indicators; q – quality indicator; k is a shape parameter that affects the function, it is used to evaluate processes of different importance with different quality requirements [15].

The coefficients a and b are found as:

$$b = b_1 \frac{1}{(q_{min} - q_{max})}, \quad (2)$$

$$b_1 = \frac{(1 - q_{max})q_{min}}{(1 - q_{min})q_{max}}, \quad (3)$$

q_{min} and q_{max} – are the minimum and maximum permissible value of a single quality indicator.

After normalization, the coefficient a is found as:

$$a = \frac{(1 - q_{min})}{q_{min}} b^{kq_{min}}. \quad (4)$$

Function (1) has an inflection point at $q_{inf} = \frac{\ln a}{k \ln b}$.

The shape parameter k affects the steepness of the function along the OX axis. By changing k , it is possible to control the curvature of the function (1) and thus obtain different estimates with the same results of the quality indicator measurements.

In graphic form, dependence (1) at $k=1$ is shown in Figure 1. On Figure 1 quality indicator is conditionally selected, which varies from $S_{min}=0.1$ до $S_{max}=0.2$ with a step of 0.01 to visually show the type of dependence (1). Regardless of the units of measurement and the digits of the value of the quality indicator on the OX axis, the type and form of the dependence will not change. A change in the shape parameter – k will lead to a change in shape. How to choose this parameter is the goal of further research.

Figure 2 shows a series of five dependences, with k varying from 1.2 to 0.8 in steps of 0.1 from left to right. On the OX axis, the scale corresponds to the scale of measurement units and can be changed for each individual quality indicator. The leftmost value on this scale “0” corresponds to Q_{min} – the minimum permissible value of the quality indicator. The extreme right value on this scale “1” corresponds to Q_{max} – the maximum permissible value of the quality indicator. They correspond to the respective values of each individual quality indicator. So, if the object of qualimetry has n quality indicators, then for each of them it is necessary to determine the coefficients a and b according to formulas (4) and (2), respectively.

Figure 2 shows that with a quality indicator of 0.6, measured in units of measurement, its assessment on a dimensionless scale varies from 0.95 at $k=1.2$ to 0.43 at $k=0.8$. So, having one measured value of the quality indicator of any object of qualimetry, we can obtain a range of values of its estimates on a dimensionless

scale. Such a situation allows you to choose one of the power indicators in function (1) and change the estimate of the measured quality indicator q on a dimensionless scale.

The size of the interval of quality indicators estimates on a dimensionless scale with different parameters of the form k is shown in Figure 3.

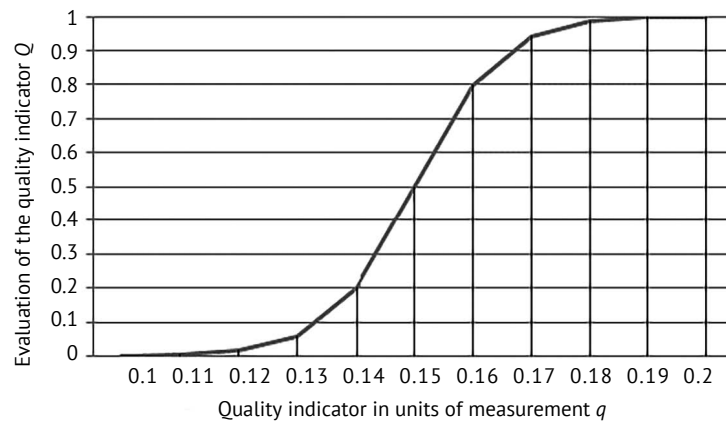


Figure 1. Type of dependence (1) at $k=1.0$

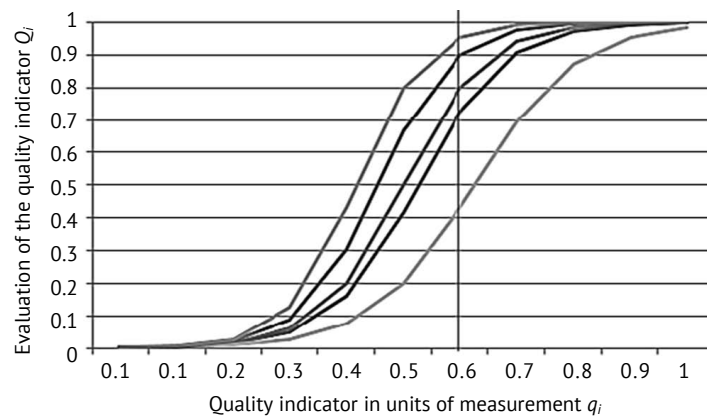


Figure 2. Series of dependencies (1) at $k=1.2-0.8$ with a step of 0.1 from left to right

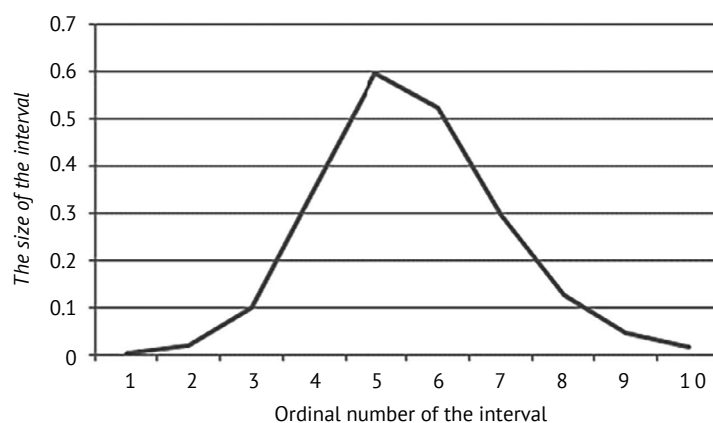


Figure 3. The value of the interval of quality indicators estimates on a dimensionless scale with different shape parameters k

To obtain the values of the intervals, the value of the tolerance field $T=q_{max}-q_{min}$ was divided into ten parts, and the values of the intervals in each of them were determined. As shown in Figure 3, the largest interval of

quality indicators on the dimensionless scale is in the middle of the tolerance field and is 0.6. Approaching the extreme values, the interval of estimates practically does not change. Therefore, it can be concluded that in

the middle of the tolerance field, the shape parameter k has the greatest influence on the quality assessment.

In order to effectively apply the proposed mathematical relationship between the measured quality indicators and their assessment on a dimensionless scale in practice, when assessing the quality of qualimetry objects, it is necessary to know their numerical characteristics. This will make it possible to create a standardized methodology that will be universal and can be applied in the assessment of any objects of quality measurement, regardless of their complexity, etc.

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Let's consider a number of practical problems that may arise when evaluating objects of quality measurement [16]. For example, if we take the desirability function (1) and set by a fixed parameter of the form k , then it is possible to find the limits within which the quality indicator q must fall, provided that the value of its assessment Q_i is in the given interval $[Q_{min}-Q_{max}]$. Since the quality assessment interval on the dimensionless scale varies from "0" to "1", the condition must be fulfilled:

$$0 < Q_{min} < Q_i < Q_{max} < 1, \quad (5)$$

where Q_{min} and Q_{max} are the lower and upper limits of the given interval of assessment of Q_i on the dimensionless scale OY. Therefore:

$$Q_{min} = f(q_{min}) \frac{1}{1+ab^{-kq_{min}}}, \quad (6)$$

where q_{min} – the value of the quality indicator on the OX axis, which corresponds to its Q_{min} rating on the OY scale at the given shape parameter k . After performing the transformation, we will obtain the minimum value of the quality indicator q_{min} – on the OX axis, which corresponds to its estimate Q_{min} on the OY scale with the given shape parameter k :

$$q_{min} = \frac{1}{-k \ln b} \ln \frac{1-Q_{min}}{aQ_{min}}. \quad (7)$$

Accordingly, in the same way we can obtain the maximum value of the quality indicator q_{max} – on the OX axis, which corresponds to its estimate Q_{max} on the OY scale at the given shape parameter k :

$$q_{max} = \frac{1}{-k \ln b} \ln \frac{1-Q_{max}}{aQ_{max}}. \quad (8)$$

Note that the length of the interval in which the measured indicator of the quality of the object of qualimetry should be located will be:

$$L = q_{min} + q_{max} \left(\frac{1}{-k \ln b} \ln \frac{1-Q_{max}}{aQ_{max}} \right) - \left(\frac{1}{-k \ln b} \ln \frac{1-Q_{min}}{aQ_{min}} \right). \quad (9)$$

Let the limits of estimates of the quality indicator of the object of quality measurement Q_i be specified in the given interval $[Q_{min}-Q_{max}]$ as follows:

$$0 < Q_{min} < Q_i < Q_{max} < 1, \quad (5)$$

and the measured value of the quality indicator q_i is known, then it is possible to find the interval for the measured quality indicator q , at which the fulfillment of the condition (5) will be guaranteed. In other words, let's define all the functions that, at a given (measured) value of q , will provide a given quality assessment on a dimensionless scale.

As a result of algebraic transformations, we get an interval:

$$\frac{1}{-k \ln b} \ln \frac{1-Q_{max}}{aQ_{max}} > q > \frac{1}{-k \ln b} \ln \frac{1-Q_{min}}{aQ_{min}}. \quad (10)$$

So, in this way, it is found the interval in which the measured quality indicator q should be at the given evaluations on the dimensionless scale OY.

Let's set one more possible condition. Let a fixed estimate of the indicator $Q_i=x$ be given, while the measured value of the quality indicator q is in the interval $[q_{min}-q_{max}]$, then it is possible to determine the range of values of the shape parameter k , at which the given conditions will be fulfilled [17]. In other words, let's define all the functions that, given the range of given (measured) values of q , will provide a given quality estimate $Q_i=x$ on a dimensionless scale. To solve this problem, it is solved equation (1):

$$f(q) = \frac{1}{1+ab^{-kq}}. \quad (1)$$

According to condition (5):

$$0 < Q_{min} < f(q) < Q_{max} < 1. \quad (11)$$

So:

$$Q_{min} < \frac{1}{1+ab^{-kq}} < Q_{max}. \quad (12)$$

As a result of mathematical transformations, we will obtain an interval for parameters of the form k of function (1), in which condition (11) will be fulfilled:

$$\frac{1}{-q \ln b} \ln \frac{1-Q_{max}}{aQ_{max}} < k < \frac{1}{-q \ln b} \ln \frac{1-Q_{min}}{aQ_{min}}. \quad (13)$$

So, with the help of desirability functions, it is possible to determine a number of useful numerical characteristics of process quality indicators, using which you can manage quality estimates, reduce or increase them, which will allow you to effectively manage the quality of qualitative objects of various nature.

As a result of the given formulas, we can get an estimate of a single quality indicator on a dimensionless scale. But, as a rule, it is necessary to know the estimate of the generalized dimensionless quality indicator, which consists of n indicators. As a generalized indicator of quality, it is suggested to find one of the averages: arithmetic average; medium harmonic; geometric mean.

Taking into account the ideology of quality assessment, it is proposed to use the geometric mean value of individual quality indicators as a generalized indicator, since the geometric mean is less than the arithmetic mean value and, most importantly, if at least one of the quality indicators Q_i is zero, then the generalized value of the quality indicator W will also be zero. Also, $W=1$ if and only if all single quality indicators $Q_i=1$. In addition, note that the generalized value of the quality indicator W is very sensitive to small values of the single quality indicators Q_i . That is, if one of the individual quality indicators is close to zero, it will significantly affect the generalized quality indicator.

So, the generalized quality assessment can be found using the formula:

$$W = \sqrt[n]{\prod_{i=1}^n Q_i}, \quad (14)$$

where Q_i – value of the i -th quality indicator on a dimensionless scale. Also, to determine the generalized quality indicator, it is possible to recommend an assessment in a different form, for example, determine W by the formula of the harmonic mean, since the geometric mean of positive values is greater than or equal to their harmonic mean

$$\frac{1}{W} = \frac{1}{n} \sum_{i=1}^n \frac{1}{Q_i}, \quad (15)$$

where Q_i is a unit estimate of the i -th quality indicator, calculated according to formula (1).

Another generalized quality estimate W can be proposed as the arithmetic mean of the single values Q_i determined by formula (1), since the arithmetic mean is greater than the geometric mean and the harmonic mean:

$$W = \frac{1}{n} \sum_{i=1}^n Q_i. \quad (16)$$

By choosing a method for obtaining a generalized quality indicator, you can lower or raise the requirements for object quality assessment.

We offer a step-by-step method for determining the generalized indicator of the quality of the object of qualimetry:

1. Determination of single indicators of the quality of the object of qualimetry. As a rule, those quality indicators that are decisive for this object, established by regulatory documents, determined by the consumer (customer) and managed are defined. They can be identified by a group of experts.

2. For each of the unit quality indicators, their maximum permissible, minimum permissible and optimal (best) values are determined.

3. These quality indicators are measured, and the results are recorded in a specially prepared table.

4. Formula (1) determines the assessment of a single quality indicator on a dimensionless scale. For this, it is necessary to use formulas (2-4) and assign the shape parameter k . The form parameter is determined depending on the level of the quality indicator: high, medium, low or general, and depending on the importance and responsibility of the indicator. The form parameter is assigned either by a group of experts or by the customer (consumer).

5. The level of the generalized quality indicator is determined: high, medium or low, depending on the importance and responsibility of the object. It is recommended to use formula (14) at a high quality level, (15) at an average level, and (16) at a low level. In any case, determining the method of obtaining a generalized quality indicator is a debatable task and is decided in each individual case.

CONCLUSIONS

To maintain a high level of product quality, there should be a single approach to evaluation that will be applied at all stages of the product production cycle. A typical product production cycle includes the stages of its creation from raw materials to finished products. Each of these stages has its own quality indicators, established in regulatory documents of different levels and periods of publication with different units of measurement.

Based on the analysis of scientific sources and existing non-linear relationships between the measured quality indicator and its assessment on a dimensionless scale, a technique based on the use of generalized quality indicators is proposed.

The proposed methodology can be used to evaluate the quality of objects of various nature, including products, technological processes, systems, or anything that is subject to evaluation. If you evaluate objects in a certain order, you can build a time series of changes in quality indicators over time and get additional generalized information for making management decisions. When using this technique, a number of advantages are achieved, which include increasing the methodical reliability of quality assessment, reducing the list of controlled indicators, the possibility of unifying diagnostics, etc.

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Узагальнений показник якості об'єктів кваліметрії різної природи

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Анотація. Виготовлення якісної продукції стимулює українських виробників до здійснення виходу на європейські та міжнародні ринки, що водночас стимулює внутрішніх виробників до випуску конкурентоспроможної продукції на рівні з високоякісними закордонними альтернативними товарами. Просування конкурентоспроможної високоякісної продукції на європейські та світові ринки дасть змогу укріпити національну валюту, що активно сприятиме покращенню економіки України, створюватиме належні умови для розвитку підприємницької діяльності, справедливої конкуренції, покращення рівня благополуччя населення. Єдиний підхід до оцінювання якості продукції покликаний оперативно відстежувати показники впродовж усього циклу її виготовлення. Для найбільш економічного і швидкого досягнення мети у сфері кваліметрії без порушення діючих обмежень постає необхідність оптимізації вимог до показників якості продукції. Існує низка методів, що мають для кожного об'єкта кваліметрії свої переваги та недоліки. Метою роботи є аналіз механізмів кваліметрії та поєднання їх переваг у спільну модель оцінювання. Дослідження проводилося із використанням методів аналізу, синтезу, порівняння, узагальнення та індукції. У статті представлено методіку визначення узагальненого показника якості об'єктів кваліметрії різної природи, серед яких: продукція, технологічний процес, система, чи будь-що, що потребує поетапного оцінювання. На основі проведеного аналізу існуючих нелінійних залежностей між вимірюваним показником якості та його оцінкою на безрозмірній шкалі пропонується метод, заснований на використанні узагальнених показників якості. Застосування запропонованого методу дозволить надати високоточну оцінку широкого спектру об'єктів з фіксацією змін у часі

Ключові слова: технологічний процес, параметр форми, цикл виробництва, використання статистичної інформації, математична залежність