Quantitative assessment of quality management systems' processes

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Based on the particularities of assessment of quality management systems, we have developed an aggregate of dependencies between the singular indicators of process quality and their values, on a dimensionless scale. The application of the aggregate allows a quantitative quality assessment of processes to be obtained and takes into account a diversity of indicators and the significance of processes in the enterprise. The application of the said dependencies allows to assessment of quality indicators and interval assessment of quality indicators. Taking into account changes of process quality over time, coefficients are developed. We have proved the use of the tests of non-parametric characteristics for the analysis of the dynamic characteristics of process quality. The results of the application of the developed methods of qualitativequality assessment in the mechanical engineering enterprises are presented.

Keywords: quality management system; quantitative assessment of processes; singular indicators of process quality; overall quality indicator; interval assessment of an indicator

JEL classification: C13, C44, C61, L15

1. Introduction

The quality of production and services of a national producer of any state is a priority in an international competitive fight since it impacts significantly on the formation of foreign policy and national safety; it determines the level of life and national currency stability. The creation of a quality management system (QMS) based on the ISO 9000 series standards contributes a lot to an enterprise's competitiveness and so to an increase of activity efficiency.

Countries of the European Union (EU), as well as those that took the decision to join the EU, are especially interested in providing high-quality products and services. The analysis of enterprises that design and implement QMS in its activities has shown that there are a number of challenges to achieving the proper functioning of the QMS.

Seeking the reasons preventing the desired effect from being achieved, we carried out a comparative analysis of quality management concepts in the activity of enterprises and modern scientific approach (Trishch & Korobko 2010). Their main focus here is the transition from quality of production to quality of processes; the proper functioning of processes will ensure the necessary level of production and services in an enterprise.

Whereas the object of management in QMS is processes, in order for management to adopt decisions, it is necessary to have information on the quality of process

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functioning. Analysis of the provisions of ISO 9000 series standards confirmed the necessity of assessment of QMS processes. In this way, Chapters 4.1; 5.6.2; 8.1; 8.2.3; 8.4 (ISO 9001:2008) contain requirements to monitor, measure, compare and analyse process quality indicators; however, the methods are not regulated by the standard, and each enterprise faces the problem of determination of process assessment separately.

2. Previous research

The analysis of the works of researchers who studied the particularities of the qualitative assessment of QMS processes in enterprises (Novikov, 2011; Stolyarchuk, Baĭtsar, & Hun'kalo, 2008) has shown that such works were based on the definition of efficiency and effectiveness; however, it is possible to get the values of those indicators after the release of products or rendering of services, but this may result in losses due to incompliances. Many works are dedicated to reasoning of different quality indicators of processes (Shichkov, 2005; Zinina, 2005) that characterise different sides of their functioning. However, there aren't methods for quantitive assessment of processes basing on such diverse indicators of different size.

There are many works of modern academic researchers (Ferreira, Santos, Rodrigues, & Spahr, 2014; Ginevičius & Podvezko, 2007; Nugaras, 2014), in which are discussed the multicriteria methods of quantitative assessment that allow one to reduce to a single scale all the object's different-sized characteristics. For example, the method SAW (Simple Additive Weighing), is the simplest and most widely applicable (Kaplinski & Peldschus, 2011; Raudeliūnienė & Račinskaja, 2014; Skačkauskienė & Kiselevskaja, 2012). Its essence lies in the determination of individual quality indicators and the values of their weights, and then finding the integral value according to the formula (Ginevičius & Podvezko, 2008; Kaplinski & Tupenaite, 2011; Raudeliūnienė, Meidutė, & Martinaitis, 2012.):

$$S_j = \sum_{i=1}^{n} \omega_i \tilde{r}_{ij} \tag{1}$$

where ω_i is the weight of the ith indicator; $\tilde{r}_{ij}$ is the normalised value of the ith indicator for the jth object, which is determined by the formula:

$$\tilde{r}_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \tag{2}$$

where r_{ij} is a value of the ith indicator for the jth object.

A no less popular method of multicriteria object assessment is TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) (Ginevičius, Suhajda, & Šimkūnaitė, 2014; Šimelytė & Antanavičienė, 2013), which aims to identify alternatives, the distance of which to the best values of the indicator will be small, and the distance to the least will be big (Beinoraitė & Drejeris, 2014; Krivka, 2014). This method is based on vector normalisation:

$$\tilde{r}_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \tag{3}$$

where r_{ij} is the normalised value of the ith indicator for the jth object.

The best alternative V' and the worst alternative V^- are calculated by the formulas:

$$V' = \left\{ V_1', V_2', ..., V_m' \right\} = \left\{ \left(max\omega_i \tilde{r}_{ij} / i \in I_1 \right), \left(min\omega_i \tilde{r}_{ij} / i \in I_2 \right) \right\} \tag{4}$$

$$V^- = \left\{ V_1^-, V_2^-, ..., V_m^- \right\} = \left\{ \left(min\omega_i r_{ij}/i \in I_1\right), \left(max\omega_i \tilde{r}_{ij}/i \in I_2\right) \right\} \quad (5)$$

where I_1 is a set of indices of maximised indicators; I_2 is a set of indices of minimised indicators; ω_i is the weight of the ith indicator ($\sum_{i=1}^{m} \omega_i = 1$).

The distances of every alternative to the best solutions are calculated by the formulas:

$$D_j' = \sqrt{\sum_{i=1}^{m} \left(\omega_i \tilde{r}_{ij} - V_i'\right)^2} \quad (6)$$

$$D_j^- = \sqrt{\sum_{i=1}^{m} \left(\omega_i \tilde{r}_{ij} - V_i^-\right)^2} \quad (7)$$

The coefficient C_j' of the TOPSIS method is calculated by the formula:

$$C_j' = \frac{D_j^-}{D_j' + D_j^-} \quad (8)$$

The largest value of the criterion C_j' corresponds to best variant.

These multicriteria methods have been further developed as, PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluation) (Ginevičius & Podviezko, 2013), MOORA (Multi-Objective Optimization by Ratio Analysis) (Brauers, Ginevičius, & Podviezko, 2014), WASPAS (Weighted aggregates sum product assessment) (Hashemkhani Zolfani, Maknoon, & Zavadskas, 2015), and have been widely used to assess various social objects, including the processes in organisations.

However, each enterprise is unique and each enterprise differs in its contents and weighting of processes, their output and input, quality indicators and their limiting values, and so on. Therefore, this research is directed to the development of a single approach to the assessment of QMS process quality that will allow us to take into account different weightings of processes in the system as well as allow not only point assessment of quality indicators but also interval assessment.

3. Theoretical basis of assessment of QMS processes in an enterprise as the system of mutually related processes

Based on the analysis of the requirements of ISO 9000 series for signs of classification systems it was found that the QMS at the enterprise is a system of interrelated processes, which is peculiar to the following specific features (Trishch, Gorbenko, Katrych, & Denysenko, 2013).

3.1. Diversity of scales and limits of process quality indicators assessment

In order to estimate the quality of processes, indicators of different measurement units are used. For example, the process of production at the enterprise can be estimated according to the value of deviation of products' characteristics from nominal data, quantity of proper products, time used for technological process, level of discipline at the work place, etc. Therefore, in order to estimate processes, methods that allow us to obtain dimensionless values of quality indicators should be applied.

3.2. *Different weighting of processes*

The requirements of ISO 9001:2008 distinguish four groups of processes: management activity, resource supply, production issue, measurements and improvements. Any process is a part of some sub-system and performs some functions for the achievement of goals of quality; it has a significant or secondary impact on final production quality; that is, the role and significance of processes in QMS are different; therefore, it is necessary to pay attention to their weightings.

3.3. *Absence of information on distribution of indicators as random values*

QMS is unique in every enterprise: it differs in its elements, quality of functioning and level of mutual relationships, as well as in on what internal and external factors have impact. Moreover, each separate process in each enterprise is estimated based on different quality indicators. Thus, the rule of distribution of process quality indicators as of random values is unknown. Therefore, methods not requiring knowledge of the distribution rule should be applied for process assessment in time.

3.4. *Absence of regularity of behaviour of process characteristics in time*

The processes are able to transit from one state to another under the impact of many factors. However, this transit cannot be performed instantly, but it requires some time. Therefore, it is necessary to estimate the characteristics of processes in dynamics. This will allow us to trace the regularity of change of process state for further research and application of management acts.

These particularities show the complexity of assessment of process quality. However, taking into account these particularities would allow us to define the mathematical basis for the development of necessary methods.

Let us consider the problem of getting a unified estimate (overall index) that expresses quality in quantity by means of its separate indicators where each has its own measurement scale and limited values. One of the methods for the problem solution is the reduction of indicators of process quality of different dimension to dimensionless quantative scale. There are methods that apply mathematical dependencies between the measured value of a quality indicator and its estimate, giving a quantitative description of quality of the estimated object (Azgaldov, 1973). However, the development of such a mathematical relationship is difficult as it requires a deep and thorough examination of the object; it is impossible to develop such a relationship for all processes since there are an infinite number of them and their properties change constantly. As a result, it can be concluded that for quantitative assessment of the quality of diverse QMS processes, the enterprises with their diverse quantity of quality parameters should select a unified relationship. It should be convenient for any processes and indicators despite their variety and level of complexity.

In order to resolve this problem, we offer to consider a nonlinear function that belongs to the theory of extreme statistics. It was applied first by E. Harrington (1965) for the assessment of economic indicators of enterprises. In time, this function was applied for assessment of production quality (Trishch & Slityuk, 2006)

$$F_1(x) = exp(-exp(-x)) \qquad (9)$$

where $x-$ values are on an additional scale that match the limiting values of process quality indicators

Since the processes in the enterprise have different characteristics (different degrees of importance and influence on the final product), the quality requirements can be reduced or enlarged. Thus, it is necessary to have not one, but several dependencies that allow us to make quantitative assessment of the quality of any process

4. Qualitative assessment of quality of processes at an enterprise

Having the function of distribution of maximum value in series $F_1(x)$ (equation (9)), applying concept of symmetry ($F(-x) = 1 - F(x)$) (Gumbel, 1965), it is possible to define the function of the distribution of minimal and average value in series (Trishch, 2013):

$$F_5(x) = 1 - exp(-exp(x)) \qquad (10)$$

$$F_3(x) = \frac{(exp(-exp(-x)) + 1 - exp(-exp(x)))}{2} \qquad (11)$$

In addition, interim dependencies between quality indicators of different dimensions and their values on a dimensionless scale will allow to optimize the requirements for functioning of processes:

$$F_2(x) = \frac{F_1(x) + F_3(x)}{2} = \frac{3exp(-exp(-x)) + 1 - exp(-exp(x))}{4} \qquad (12)$$

$$F_4(x)\frac{F_3(x) + F_5(x)}{2} = \frac{exp(-exp(-x)) + 3(1 - exp(-exp(x)))}{4} \qquad (13)$$

Thus, for assessment of some process in the enterprise, one of five dependencies between singular indicators of the process quality of different dimensions and their values on a dimensionless scale may be used (Figure 1). Application of the said dependencies will give different assessments and allow an increase or decrease of requirements to process quality. So, $F_1(x)$

$F_1(x)$ corresponds to the maximal value in series and when choosing this relationship we put a higher requirement for the process quality. It can be seen on Figure 1 that when $x = 0$, the value on dimensionless scale is $F_1(x) = 0.37$;

$F_5(x)$ corresponds to the minimal value in series and when choosing this relationship we put a lower requirement for the process quality. When $x = 0$ the value on dimensionless scale is $F_5(x) = 0.63$;

$F_3(x)$ corresponds to the average value in series, and it may be used by the management of the enterprise for assessment the average requirements for the process quality. When $x = 0$ the value on a dimensionless scale is $F_3(x) = 0.5$;

$F_2(x)$and $F_4(x)$ correspond to the interim values between F5(x) and F3(x), as well as between F1(x) and F3(x),; they are necessary in order to increase the accuracy of assessment of processes, since many processes are performed on each enterprise and it is important to have several relationships for their assessment. When $x = 0$ the values on the dimensionless scale, if these dependencies are used, correspond to $F_2(x) = 0.43$ and $F_4(x) = 0.53$.
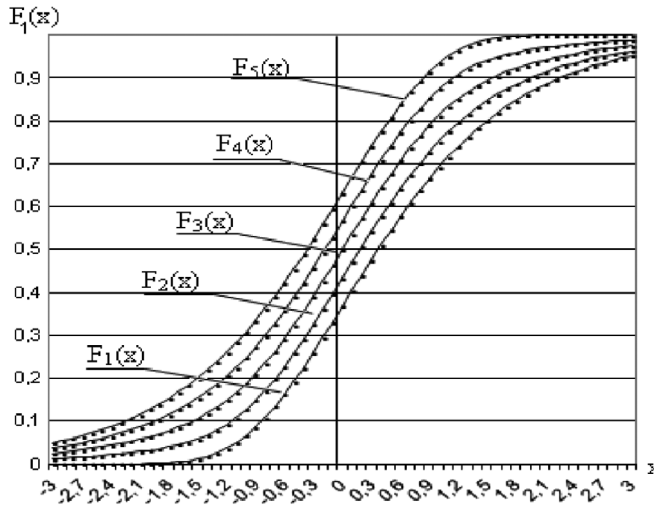
Figure 1. Dependencies between indicators of process quality of different dimensions and their values on a dimensionless scale.
Source: Author analysis.

Moreover, using a pair of the said dependencies allows us to obtain an interval of the values of a quality indicator and so establish the requirements for the functioning of a process.

In order to select the required function for assessment of the defined process, we suggest using the method of hierarchy analysis (Ginevičius & Podvesko 2008; Saaty, 1980, 2005) based on a determination of weighting of objects using paired comparisons. The essence of this method is to present the problem as a hierarchy, where the first level is the very problem (determination of a function for assessment of the process), on the second level there are criteria according to which the function is determined (installed by expert method), and on the third level there is a list of alternative solutions, that is, functions $F_i(x)$ themselves. The criteria are compared with each other in pairs with respect to the influence on the ultimate goal. To do this, the assessment scale proposed by the author is used. Based on the results of pairwise comparisons, a square matrix is constructed $A = (a_{ij})$, where (a_{ij}) is the relationship between the criteria (indicators i and j are changed from 1 to the number of criteria):

$$
\begin{pmatrix}
a_{11} & a_{12} & a_{13} & a_{1n} \\
a_{21} & a_{22} & a_{23} & a_{2n} \\
a_{31} & a_{32} & a_{33} & a_{3n} \\
a_{n1} & a_{n2} & a_{n3} & a_{nn}
\end{pmatrix}
\tag{14}
$$

Similar matrices are constructed for paired comparisons of each function of process assessment $F_i(x)$ at the third level in relation to criteria for level 2. Further, by finding component eigenvectors as the geometric mean of the matrix by row $(a_j = \sqrt[n]{a_{11} \cdot a_{12} \cdot a_{13} \cdot a_{1n}})$, the overall significance of the solution is found $(X_i = \frac{a_j}{S}$, where S is the sum of vectors) at the option of one or another function of process estimation. A special feature of this method is the built-in quality criterion of the experts – the indicator of consistency.

The function established in the said way provides estimates of singular process quality indicators of different dimensions on a dimensionless scale $F(x)$. To determine the generalised process quality, it is recommended to apply one of the means (arithmetic, geometry, harmonised), which allow linking together the separate estimates.

According to Figure 1, the values on the additional scale change $-3 \leq x \leq 3$ and estimates on the dimensionless scale correspond to $\begin{cases} F(x) = 0, when\, x = -3 \\ F(x) \rightarrow 1, when\, x = 3 \end{cases}$

However, the analysis of process quality indicators has shown that this condition is not always satisfiable. Perhaps, the value of the quality assessment indicator is $F(x) \rightarrow 1$ when $x = -3$, which corresponds to the lowest limit value of the singular process quality indicator, which in this case is optimal (best value); for example, for the number of inconsistencies found during the operation of the process: the lower value, the better. Therefore, the process quality indicators were classified according to optimality (Figure 2); as a result, four groups were determined

- A group of quality indicators for which the optimal (best) value tends to the upper limit of tolerance ('tolerance band' refers to the field, limited with the highest and lowest acceptable values of quality). For example: reliability, performance, attendance of students, etc. In this case, the higher the value of this index, the better;
- A group of quality indicators for which the optimal (best) value tends to the lower limit of tolerance. For example: the number of accidents, incompatibilities during the operation of the process, etc. In this case, the lower the value of this index, the better;
- A group of quality indicators for which the optimal (best) value tends to the middle of tolerance. For example: the accuracy of product parameters, point of indoor temperature, time of performance, and so on;
- A group of quality indicators for which the optimal (best) value tends to the edges of tolerance. For example, the highest productivity at the lowest cost, and so on.

Based on this classification, by changing the value on the auxiliary scale, we obtained four types of functions between heterogeneous indicators of process quality and their estimates on the dimensionless scale that allowed the development of a unified system of functions of process assessment (Figure 3). Thus, the process assessment can be performed on one of 20 choices depending on the conformity of singular quality

Group 1	A group of quality indicators for which the optimal (best) value tends to the upper limit of tolerance.
Group 2	A group of quality indicators for which the optimal (best) value tends to the lower limit of tolerance.
Group 3	A group of quality indicators for which the optimal (best) value tends to the middle of tolerance.
Group 4	A group of quality indicators for which the optimal (best) value tends to the edges of tolerance.

Figure 2.   Classification of quality indicators of QMS processes according to optimality.
Source: Author analysis.

indicators with one of four characteristics of the proposed classification (that match the scales: x_1, x_2, x_3, x_4) and weighting of the process.

In the enterprise, the measured values of process quality are fixed at regular intervals, e.g. when conducting internal audits or routine monitoring of the process. As a result of such a time, a series of measurements is obtained (Figure 4).

T is tolerance, limited with the highest and lowest acceptable values of the quality indicator; X_{max} and X_{min} are, consequently, the highest and the lowest measured values;
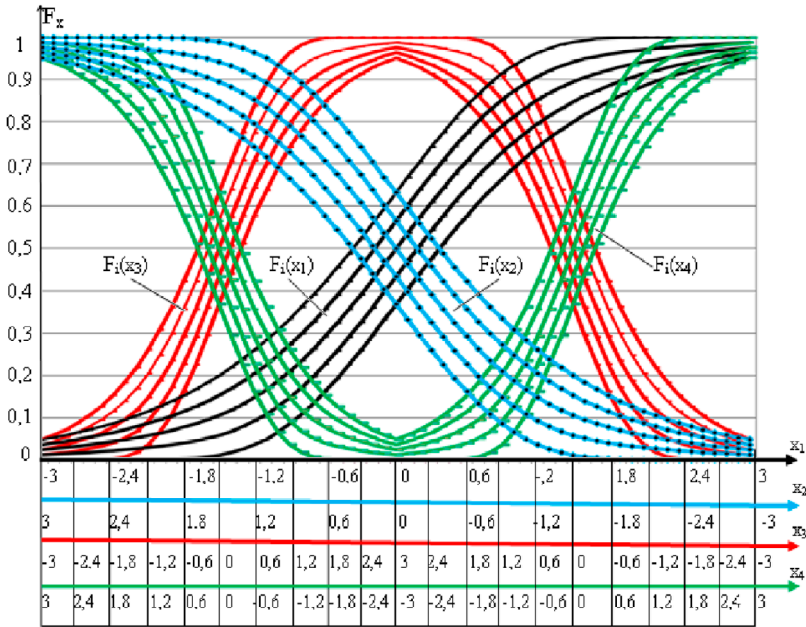

Figure 3.   The system of relationships of assessment of process quality.
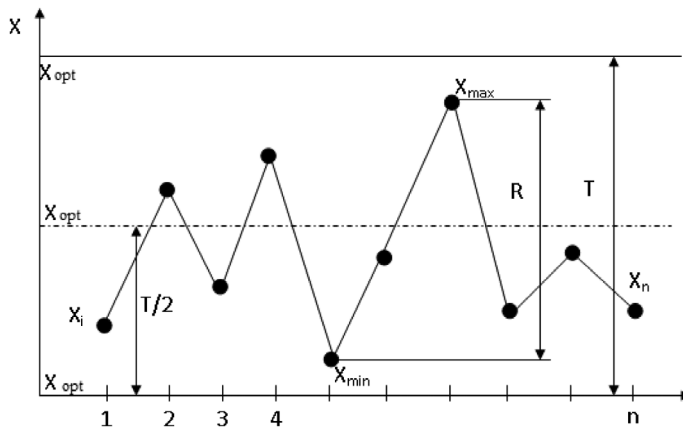Source: Author analysis.

Figure 4.   General scheme of QMS process functioning.
Source: Author analysis.

R is field between $X_{\max}$ and $X_{\min}$; X_{opt} is the best value of the quality indicator (the value to aspire).

In a complex survey of process quality indicators, interest constitutes not the average values that are applicable to the products' quality study (Trishch & Slityuk, 2006), but the values showing the difference between the measured values and the optimum. Average estimates reduce the amount of important information and are not always objective characteristics of the process, for example, the average air temperature in the operating room. Getting the value $K = \frac{R}{T}$ is inadmissible in this case; the difference of X_{man} and X_{min} from X_{opt} should be considered. Therefore, in order to determine the parameters of process quality, a complex of limiting factors, equations (15) – (18), is developed that is based on the use of order statistics ($X_{\min}$ and $X_{\max}$), and allows one to obtain:

- The value of a single indicator of the process quality within a certain period (K_p), and at a particular moment ($K_{p(t)}$);
- The value of the reserve dispersion of the single process quality indicator within a certain period (K_r), and at a particular moment ($K_{r(t)}$).

Dispersion coefficient:

$$K_p = \begin{cases} \frac{X_{min} - X_{opt}}{T}, \, when \, |X_{min} - X_{opt}| > |X_{max} - X_{opt}| \\ \frac{X_{max} - X_{opt}}{T}, \, when \, |X_{min} - X_{opt}| < |X_{max} - X_{opt}| \end{cases}, \tag{15}$$

Instantaneous dispersion coefficient:

$$K_{p(t)} = \begin{cases} \frac{X_{min}(t) - X_{opt}}{T}, \, when \, |X_{min}(t) - X_{opt}| > |X_{max}(t) - X_{opt}| \\ \frac{X_{max}(t) - X_{opt}}{T}, \, when \, |X_{min}(t) - X_{opt}| < |X_{max}(t) - X_{opt}| \end{cases}, \tag{16}$$

Reserve dispersion coefficient:

$$K_r = 1 - \begin{cases} \frac{X_{min} - X_{opt}}{T}, \, when \, |X_{min} - X_{opt}| > |X_{max} - X_{opt}| \\ \frac{X_{max} - X_{opt}}{T}, \, when \, |X_{min} - X_{opt}| < |X_{max} - X_{opt}| \end{cases}; \tag{17}$$

Instantaneous reserve dispersion coefficient:

$$K_{r(t)} = 1 - \begin{cases} \frac{X_{min}(t) - X_{opt}}{T}, \, when \, |X_{min}(t) - X_{opt}| > |X_{max}(t) - X_{opt}| \\ \frac{X_{max}(t) - X_{opt}}{T}, \, when \, |X_{min}(t) - X_{opt}| < |X_{max}(t) - X_{opt}| \end{cases}. \tag{18}$$

In view of the proposed classification of process quality indicators according to optimality (Figure 2), these coefficients can be determined for all four groups; depending on X_{opt}. This allows us to obtain data of the process quality indicator in quantitative terms.

The application of the developed dependency system between the different sizes of singular quality indicators and their values on a dimensionless scale allows us to quantitatively estimate the process in the prescribed time. However, processes during a particular period of time are able to pass from one state into another under the influence of a number of factors. Thus, the assessment of process quality cannot be limited to point assessment, but has to include analysis of process characteristics over time.

Parametric statistics are usually used to estimate dynamic characteristics, in other words, methods that require knowledge of a random distribution law. Since such a law is unknown regarding the distribution of indicator values of process quality of QMS, we

shall apply methods that do not depend on knowledge of random distribution that are distribution-free (non-parametric) statistics (Bolshev, 1983; Kolker, 1976).

At the same time, before using methods of distribution-free (non-parametric) statistics to estimate dynamic characteristics, it is necessary to analyse historical data concerning the absence of crude errors. In fact, during the study of process quality there can be cases when experimental data containing crude errors appear as a result of measurement or monitoring of processes, application of unreliable information as well as during the calculation of the composite index of quality, etc. Such errors can have a decisive influence on the processes quality assessment, and, in the future, the bias of the taken decisions. To analyse the data of a composite index of process quality over time in order to exclude crude errors we shall use Romanovsky's criterion (Gumbel, 1965) according to which it is necessary to define statistical characteristic of process: $\bar{X}$ arithmetic middling timing series and σ mean-square deviation as well as value: $r = \frac{\left|F_{x_i} - \bar{X}\right|}{\sigma}$. The $r < r'$ condition (r' – tabulated data (Gumbel, 1965)) denotes the absence of crude errors.

The next step is to determine the stationary state of the process, since it has been known that one can manage a process where statistical characteristics do not vary over time. In order to confirm the stationary state of processes we propose using criterion of non-parametric statistics – the reversal test since it is more powerful in comparison with other criteria (Bolshev, 1983). For this purpose a number of cases shall be determined when $F_{x_i} > F_{x_j}$ while $i > j$ (j = all further values of quality composite index in time series). Each such inequality is a reversal. The number of reversals is determined from the formula: $A = \sum_{i=1}^{n-1} A_i$, where: $A_i = \sum_{j=i+1}^{n} h_{ij}$ is a number of cases when each ith value is greater than all the following (for example, $A_1 = \sum_{j=2}^{N} h_{1j}$, $A_2 = \sum_{j=3}^{N} h_{2j}$, $A_3 = \sum_{j=4}^{N} h_{3j}$ etc.), and $h_{ij} = \begin{cases} 1 - if\ F_{x_i} > F_{x_j} \\ 0 - if\ other\ F_{x_i} \end{cases}$. The process is considered to be stationary, if the condition is fulfilled: $A_{n;1-\frac{\alpha}{2}} < A < A_{n;\frac{\alpha}{2}}$; where $A_{n;1-\frac{\alpha}{2}}, A_{n;\frac{\alpha}{2}}$ are lower and upper limits (tabulated data) (Bolshev, 1983).

We propose to use run a test to determine the period of the effect of chance and regular factors on process functioning (Bolshev, 1983). In accordance with this it is necessary to find values $F(x) > S$, having denoted '+', (S = average number) and $F(x) < S$, having denoted '−'. The values' sequence with the same '+' or '−' sign is a series. To confirm chance we shall check the condition: $g(\alpha; N_1; N_2) < r < G(\alpha; N_1; N_2)$, where $g(\alpha; N_1; N_2)$ is the lower critical value for a number of series r; $G(\alpha; N_1; N_2)$ is the upper critical value for a number of series r ($g(\alpha; N_1; N_2)$ and $G(\alpha; N_1; N_2)$ are table values, depending on α, the confidence level; N_1, the number of elements with a '+' sign; N_2, the number of elements with a '−' sign) (Bolshev, 1983).

The fulfilment of the condition of chance confirms that chance factors that are not subject to management have an effect on the process of QMS. When the chance condition is not fulfilled, regular factors influence the process flow.

The sequence of determination of the process behaviour patterns of the QMS in time will be shown on the example of the process of mechanical processing of an element of an internal-combustion engine (EICE).

5.   Results of the developed methods for assessment of quality processes

To confirm the capacity of the developed methods and techniques to provide a general quantitative assessment of the process's quality, research was performed at the engineering enterprise 'AVTRAMAT' (Ukraine, Kharkov). For the assessment, we considered the process of mechanical processing of EICE. At this enterprise the assessment of the present process is performed according to the following indicators: accuracy of diametrical sizes; shift of the axis of finger holes from the axis of the piston; noise level in the room; total vibration during operation of the process; average time spent in the machining operation of parts; the number of non-defective products; the level of the technological discipline.

The result of applying the analytic hierarchy showed that for assessment of the process, the function $F_1(x)$ should be used (Figure 1). For pair comparisons, the following criteria were considered: the level of influence of the process on the quality of finished products; the amount of output information flows; the number of workers engaged by the process; the resources spent for implementation of the process; output material flows; place of the process in the QMS; relationship with other processes.

Three experts took part in the choice of criteria and paired comparisons; their quality of work was verified by the index of consistency. In result of experiment, the comparison of the index of consistency with average consistency for the matrix of the seventh order is 8% that corresponds to the condition of ≤ 10%.

The acquired experimental values of the above process quality parameters and results of mathematical transformations using time-dependency system works are given in Table 1.

Thus, the application of the developed system of relationships between singular indicators of different sizes of process quality and their values on the dimensionless scale provides a quantitative assessment of the quality process in the enterprise at a given

Table 1.   Results of application of the developed system of functions of singular indicators of process quality with dimensionless scale of assessment.

Name/designation		X'_{min}	X'_{max}	X'_{opt}	Measured value.	Value on an addit, scale,x_i	Value on the dimensionless scale, $F(x_i)$
External diameter, mm	D	82.862	82.872	82.867	82.867	−3	0.95
Diameter of finger hole, mm	d	21.974	21.984	21.979	21.979	−2.4	0.91
Shift of the finger hole axis, mkm	S	−50	50	0	5	−2.4	0.91
Noise, dB	N	40	140	40	83	−0.42	0.52
Vibration, m/s^2	V	0.1	1.5	0.1	0.8	−3	0.95
Average time, xt	T_{av}	0.4	0.6	0.5	0.54	−0.6	0.58
Level of nondefective production. %	K	90	100	100	99	−2.4	0.91
Level of the technological discipline	L	0	5	5	4	−1.8	0.85

Note: The general indicator of the machining process quality was defined as the geometric mean of the assessments of individual indicators: $F_1(x) = \sqrt[8]{0.95\ 0.91\ 0.91\ 0.52\ 0.95\ 0.58\ 0.91\ 0.85} = 0.8$
Source: Author analysis.

Table 2.   The statistical data of composite index of quality of mechanical processing.

No.	x	y	m	No.	x	y	m
1	0.66	0.69	0.7	13	0.66	0.73	0.7
2	0.68	0.7	0.7	14	0.68	0.75	0.74
3	0.5	0.6	0.73	15	0.7	0.76	0.75
4	0.53	0.57	0.75	16	0.7	0.77	0.76
5	0.55	0.6	0.73	17	0.73	0.8	0.77
6	0.5	0.63	0.7	18	0.7	0.78	0.8
7	0.56	0.67	0.68	19	0.68	0.77	0.8
8	0.58	0.64	0.66	20	0.57	0.7	0.82
9	0.6	0.68	0.67	21	0.55	0.68	0.76
10	0.6	0.7	0.6	22	0.56	0.69	0.75
11	0.62	0.73	0.63	23	0.6	0.69	0.76
12	0.6	0.74	0.66	24	0.64	0.68	0.78

Source: Author analysis.

time interval. As indicated above, one particular feature of the QMS assessment is necessity of study process implementation over time, but this requires additional observations and will be the subject of our further research.

Values of these indexes were measured and fixed twice a month. Based on the application of the developed dependencies system, in order to study the process behaviour patterns, we obtained the values of the general indicator of the mechanical processing of EICE (x, y, m) quality for 3 years (Table 2). Eventually, we obtained three implementations of the process. The statistical data were checked concerning the absence of crude errors by means of Romanovsky's criterion, through the reversal test we have defined that this process was stationary. In addition. using the run test allowed us to determine that during the period being studied regular factors influenced the process.

The next step is to determine a systematic component of the composite index concentration of process quality over time. For this purpose we found the difference between every further value of a single implementation and all previous values of other implementations (equation (19)). This allowed an increasing the volume of information about the process being studied.

$$
\begin{aligned}
&x_{i+1} - x_i; x_{i+1} - y_i; \ldots; x_{i+1} - m_i \\
&y_{i+1} - x_i; y_{i+1} - y_i; \ldots; y_{i+1} - m_i \\
&y_{i+1} - x_i; y_{i+1} - y_i; \ldots; y_{i+1} - m_i
\end{aligned}
\tag{19}
$$

On the basis of all the differences we built up a set of variate values and found a median value that is a value of the systematic component of this process (Figure 5).

Therefore, the introduction into the enterprise performance of the developed dependency system between different sizes of singular quality indicators and their values on a dimensionless scale allows us to obtain process point assessment, and application of the proposed tests and criteria of non-parametric characteristics provides information on the process behaviour over time. This allows us to foresee any occurrence of non-conformity at the enterprise and so introduce preventive measures.
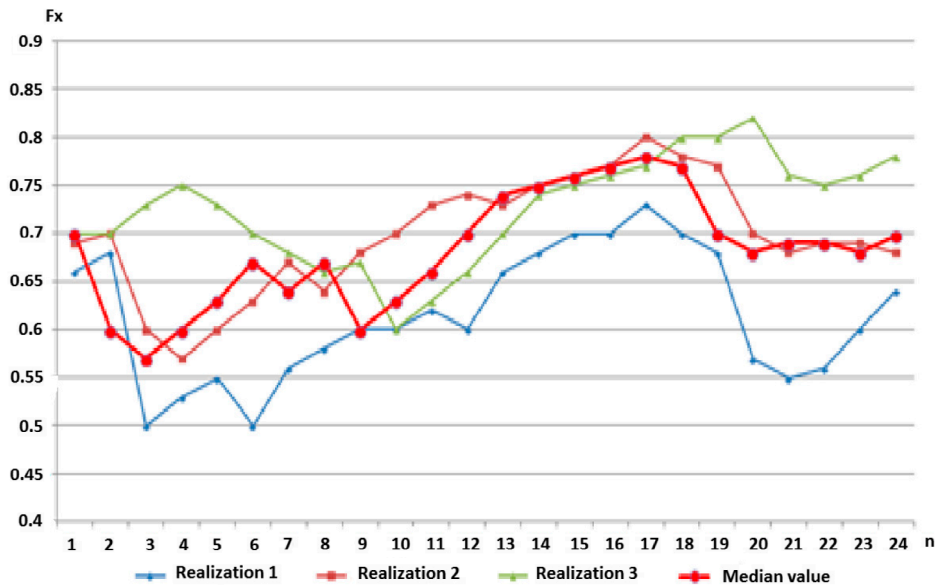
Figure 5. Value of systematic component of composite index concentration of process quality over time of its functioning.
Source: Author analysis.

6. Conclusions

1. Indicators of processes quality are classified on the basis of optimality. For each group there was developed a set of limiting factors: dispersion; instantaneous dispersion; safety factor of dispersion; instantaneous safety factor of dispersion. The use of these factors gives a picture of a single quality indicator of the process at regular time intervals.
2. Based on the proposed classification of indicators of the process quality on the basis of optimality, a system of relationships was created between different sizes of singular quality indicators and their values on a dimensionless scale, which enables us to obtain a quantitative assessment of the quality of any process in any enterprise, given its importance in the QMS .
3. We have proved the use of tests of non-parametric characteristics for analysis of dynamical characteristics of process quality that allowed us to estimate processes taking into account the time of their functioning.
4. The developed methods were tested at one particular enterprise. The results confirmed that on the basis of these methods there is the possibility to obtain a quantitative value of processes quality at a given time, and to analyse the situation during this time. All mentioned sets the basis for the products' quality improvement.

Disclosure statement

No potential conflict of interest was reported by the authors.

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