Assessment and quality management of dynamic circuit flows as a condition of enterprise safety

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Abstract. State standard R ISO 22301-2014 establishes the requirements for an effective business continuity management system to protect against incidents, reduce the possibility of their implementation, prepare response, and recover from incidents that threaten the economic and information security of the enterprise. The activities can be described through the interaction of dynamic circuit flows (information, financial, material, energy, and staff). It is legitimate to use qualimetric measurements to optimize it and reduce the risk of incidents.

1. Introduction
The Business Continuity Management System (BCMS) is a part of the organization’s overall management system, which includes organizational structure, policies, activity planning, responsibility allocation, procedures, processes, and resources.

An effective BCMS should take into account the influence of uncertainty and risk factors in the occurrence of incidents and ensure the continuity of business operations and the implementation of business processes during the incidents and breaches caused by them.

It is necessary to understand what organizational and resource conditions are necessary and sufficient to ensure the activities of the enterprise at a certain (desired) level of its productivity and efficiency, which can be a set of target values of key parameters, correspond to the needs of the organization.

There is always a certain organizational structure of an enterprise, during the operation of which with certain probability there are incidents that violate the main business processes and negatively affect the productivity and efficiency of its activities.

At least two methodological approaches to the study of probable incidents and their impact on business processes implemented by the enterprise are legitimate:

1. Presentation of an incident dependent on random factors as a multidimensional random variable, the probabilistic characteristics of which can be studied by means of a directed computational experiment (i.e., by methods of statistical modeling) to further evaluate the frequency of its occurrence and the severity of possible consequences.
2. Carrying out a number of preliminary activities and organizing their optimal resource support. These events are carried out in a certain sequence and minimize the possibility of an incident (the method of R. Bellman from the field of dynamic programming is an analogue).
The following steps are possible to solve the problem of minimizing the negative consequences of incidents for the ongoing business processes of the enterprise:

- analysis of theoretical sources on the problems of research of managerial activity in the uncertainty and risk factors environment;
- determination of theoretical, methodological, and resource bases for the development of optimal management decisions for the current conditions of the enterprise;
- development (or correction) of the existing organizational structure of management, composition, forms, and methods of implementing business processes;
- systematization, generalization, and processing of accumulated theoretical and practical materials for further practical use, staff training, etc.

2. Circuit flow model

To increase the productivity and efficiency of management within the framework of a systematic approach, it is required to use scientific methods. For complex socio-economic systems, management issues are still not well developed, and technical and industrial-technical systems are known and widely used. In other words, the number of possible options for organizational structures is infinite, but only those that have a well-defined configuration (adjusted for each specific case) are viable.

![Figure 1. Canonical model of organization.](image)

Organizational structures of similar types have similar concepts (figure 1). Within specific enterprises, they differ only in potentials and topology, i.e. location in space and the connections between their elements. These relations can be described as a system of dynamic circuit flows that reflect the real business processes of the organization.

Circuit flow is a flow of resources through a closed chain of links in the organizational structure, into which, through direct and feedback, the subjects and objects of control are combined. Now we are going to describe the structure and composition of dynamic circuit flows in the enterprise. There are the following input flows:

1. information (diverse character data on various media);
2. financial (own and borrowed funds, securities, etc.);
3. material (fixed assets, raw materials, semi-finished products, and components);
4. energy (fuel, electricity, water, etc.);
5. staff (with their skills and competencies).

The potentials of the organizational structure are human and technological ones, and at the output there is a product or service [1].

Each stream \( j \) can generate stream \( j^* \) in accordance with the accepted numbering and reproduction coefficient \( \omega_{jj^*} (j^* \neq j) \), which can be both positive and negative, depending on whether the generated stream increases or decreases (figure 2).
Moreover, each of the streams can be decomposed into separate ones from different sources, i.e. stream $S$ can be specified by a vector:

$$S = (s_1, s_2, \ldots, s_n)^T, \text{ or }$$

$$S = (s_1, s_2, \ldots, s_{nj})^T,$$

where $n_j$ is the dimension of the $j$-th resource, $j = (1, \ldots, 5)$, $T$ is the transpose operation.

Convert stream $S$ to stream $S_j^*$ is the following:

$$S_j \rightarrow S_j^* :$$

$$I^* = f_1(I \omega_{11}, F \omega_{1F}, M \omega_{1M}, E \omega_{1E}, H \omega_{1H})$$

$$F^* = f_2(I \omega_{21}, F \omega_{2F}, M \omega_{2M}, E \omega_{2E}, H \omega_{2H})$$

$$M^* = f_3(I \omega_{31}, F \omega_{3F}, M \omega_{3M}, E \omega_{3E}, H \omega_{3H})$$

$$E^* = f_4(I \omega_{A1}, F \omega_{AF}, M \omega_{AM}, E \omega_{AE}, H \omega_{AH})$$

$$H^* = f_5(I \omega_{51}, F \omega_{5F}, M \omega_{5M}, E \omega_{5E}, H \omega_{5H})$$

In this case, the dynamics of the flow paths is a set of a block balance matrix $B_{org}$, as a result of which there is the following:

$$S^* = B_{org} S =$$

$$\begin{bmatrix}
\omega_{1I} & \omega_{1F} & \omega_{1M} & \omega_{1E} & \omega_{1H} \\
\omega_{2I} & \omega_{2F} & \omega_{2M} & \omega_{2E} & \omega_{2H} \\
\omega_{3I} & \omega_{3F} & \omega_{3M} & \omega_{3E} & \omega_{3H} \\
\omega_{4I} & \omega_{4F} & \omega_{4M} & \omega_{4E} & \omega_{4H} \\
\omega_{5I} & \omega_{5F} & \omega_{5M} & \omega_{5E} & \omega_{5H}
\end{bmatrix} \begin{bmatrix}
I \\
F \\
M \\
E \\
H
\end{bmatrix}$$

Here it is supposed to be possible to consider the flows $S_j$ as a superposition of these flows. By constantly monitoring in real time the dynamics of changes in system parameters, it is possible to ensure the continuous management of production activities, which will minimize various risks, thereby increasing the level of economic and information security of the enterprise.

3. Metrological support for controlling dynamic circuit flows

Now we are going to consider the task of metrological support (MS) of the processes of converting material values into finished products for the considered model of organizational structure. MS object can be considered all stages of the life cycle (LC) of a product or service, where the LC is a set of successive interrelated processes of creating and changing the state of a product from formulating initial requirements to it until the end of operation or consumption.
The concept of constructing an organizational management structure based on a circuit flow model has a feedback. In this regard, the task of MS of the production process has a broader aspect: it is a product quality management, since it is carried out cyclically. In addition, today the development of MS is moving in the direction of the transition from the existing narrow task of ensuring unity and the required accuracy of measurements to the new task of ensuring the quality of measurements.

The concept of qualimetry is associated with the purpose of product quality management. One of the tasks of it is the development of methods for quantifying the level of product quality, finding quantitative measurements and assessments necessary to justify its level and making decisions. Metrology provides significant source material for assessing quality using qualimetry methods. The role of metrology in improving quality is due not only to the fact that a number of quality indicators are quantities controlled by measuring instruments. Modern production technologies are closely related to metrology and require the provision of the necessary values of quality indicators in the production process. This is achieved by applying methods and means of quality control at all stages of the production cycle.

Qualimetry seeks to implement a quantitative measure of both physical and all other (aesthetic, economic, social, consumer, etc.) properties of labor products and their combinations. Qualimetry also seeks to give them a qualitative assessment.

One of the ways to combine the methodology of qualimetry and metrology is to apply the concept of “qualimetric measurement” as one of the types of measurements in theory and practice of qualimetry [2].

Qualimetric measurement is the measurement of the level of product quality, the value of which is found by processing the results of measurements of its properties according to the multidimensional scaling methodology [3,4].

According to Russian State Standard 15467-79 “Product quality management. Basic concepts. terms and definitions”, the level of product quality is a relative characteristic of product quality, based on a comparison of the values of the estimated indicators of product quality with the baseline values of the relevant indicators [5].

Qualimetric measurements cannot be directly attributed to any of the types of measurements according to the recommendations on interstate standardization of the State system for ensuring the uniformity of measurements “RMG 29-2013 GSI. Metrology. Basic terms and definitions”, because: firstly, they are not direct; and secondly, they are also not indirect (since in the general case there is no known functional relationship between the level of quality as a measurable quantity and directly measured properties of the products under study), neither aggregate, nor joint (since there is one measurable quantity: quality level test products).

Therefore, the previous approach about determining the essence and purpose of qualimetric measurements allows interpreting them as one of the types of measurements and using the main principles of measurement theory for their analysis [7, 8]. According to the above definitions of the concept of measurement uniformity, described in the recommendations on interstate standardization of the State system for ensuring measurement uniformity “RMG 29-2013 GSI. Metrology. Basic terms and definitions”, its most important components are finding the result and evaluating its accuracy. The essence of any measurement is a comparison of the quantity with a measure that reproduces and (or) preserves a certain physical quantity of a given size.

The specificity of qualimetric measurements consists in the absence of specific physical ones of the quality of a particular product, and the available basic (standard) samples of the investigated products do not always correspond to the metrological requirements for the measures, and it is not always methodologically possible to compare the studied products with such a basic sample that and constitutes the main problem of the implementation of qualimetric measurements.

For MS of qualimetric measurements and assessment of their accuracy, it is proposed to use a virtual measure of product quality, which is a theoretical analogue of the corresponding physical one of the quality of the studied product [3].

Today, as a numerical estimate of the accuracy of a measurement result, its error or uncertainty is used in accordance with ISO/IEC GUIDE 98-3: 2008 “Uncertainty of measurement”. In modern
metrology, the concept of uncertainty dominates in assessing the accuracy of measurements, according to which the numerical estimation of the measurement accuracy is the uncertainty of the measurement result, designated as a parameter associated with it and characterizing the scatter of values that can reasonably be attributed to the measured value.

Accordingly, the main stages of research in the field of solving the problem of ensuring the unity of qualimetric measurements should be the following:

- analysis of the methodology of qualimetric measurement using a virtual measure of product quality in order to determine the result, i.e., quality level of the investigated product;
- development and analysis of a methodology for assessing the accuracy of measuring the quality level of Q products based on the concept of uncertainty.

4. Methodology for the implementation of qualimetric measurements using a virtual measure of product quality

To define the concept of a virtual measure of product quality, the basic principles of the theory of constructing virtual measuring instruments as one of the most modern high information technologies [10] and set theory as the corresponding section of mathematics are used. The essence of virtual measuring instruments are in a computer simulation of the operation of real physical ones, and measuring and control systems, in a virtual simulation of certain functions of a device using mathematical and software tools.

So, a virtual measure of product quality is a mapping of a real physical measure of the quality of a given product, expressed by mathematical and software tools. On the other hand, according to Russian State Standard 15467-79 “Product quality management. Basic concepts. Terms and Definitions”, it can be a set of unit absolute \( P_i \) and relative \( K_i \) indicators of product quality [5]. The absolute indicator of \( P_i \) (\( i = 1, 2, ..., n \), where \( n \) is the number of properties) characterizes the individual properties of the product, numerically equal to the value of the \( i \)-th product property \( P_i \) and is expressed in units. In the procedure for assessing product quality, it is a directly measurable quantity. The relative indicator of product quality \( K_i \) (\( i = 1, 2, ..., n \)) characterizes the individual properties of the product in a relation between the values of a particular property by its absolute indicators and is a dimensionless quantity.

Unit absolute indicators of product quality \( P_i \) (\( i = 1, 2, ..., n \)), where \( n \) is the number of unit indicators equal to the number of coordinates of the multidimensional Euclidean space, they have different physical nature and they are points on the corresponding coordinate axes of the multidimensional space. Moreover, the scales along the individual \( i \)-th coordinate axes of space are different and determined by the weight coefficients \( \alpha_i \) of the corresponding unit absolute quality indicators \( P_i \).

In qualimetry, the quality profile (QP) is a set of single indicators of product quality [3]. Product quality profiles can be formed either from absolute single indicators of product quality \( P_i : QP_P=\{P_1; P_2; ...; P_n\} \), or from relative individual indicators of product quality \( K_i : QP_K=\{K_1; K_2; ...; K_n\} \), (\( i = 1, 2, ..., n \)). There are no functional relations between the individual unit indicators of product quality that are part of the quality profile, which distinguishes the product quality profile from the mathematical quality model, in which the level of product quality is associated with its individual functional dependence.

So, QP of products is a separate integrated characteristic of its quality and it can be used to build a virtual measure.

To build a virtual measure of product quality, we use the relative unit indicators \( K_i \), \( i = 1, 2, ..., n \), which, in contrast to the absolute indicators \( P_i \) are dimensionless.

From the point of view of constructing a virtual measure of product quality, we are going to consider in more detail the classification of quality indicators according to certain criteria.

According to the form of displaying product properties, quality indicators are divided into absolute \( P_i \), and relative \( K_i \), and according to the function of the indicator, when determining the level of product
quality, they are divided into estimated \((P_{0,i} \text{ and } K_{0,i})\) and basic \((P_{b,i} \text{ and } K_{b,i})\) ones. In addition, according to Russian State Standard 15467-79 “Product quality management. Basic concepts. Terms and Definitions”, regulated limit values of absolute indicators of product quality are established: minimum \(P_{\text{min}}\) and maximum \(P_{\text{max}}\). The values of the unitary relative assessed quality indicators \(K_{0,i}\) always are within \(0 \leq K_{0,i} \leq 1\), however, depending on how the values of \(K_{0,i}\) affect the value of the level of product quality \(Q\), they change in different ways and two groups of indicators of product quality can be distinguished. In the first group of indicators, an increase in the quality level of the investigated products \(Q\) leads to an increase in the value of a unit of estimated absolute quality indicator \(P_{0,i}\) and, accordingly, an increase in a unit of estimated relative quality indicator \(K_{0,i}\), that is, \(K_{0,i} \rightarrow 1\). So, in the first group of indicators of product quality, the basic values of relative quality indicators \(K_{b,i}=0\), and the values of individual relative quality indicators \(K_{0,i}\) should be calculated by the formula:

\[
K_{0,i} = \frac{P_{0,i}}{P_{\text{max}}} = \frac{P_{0,i}}{P_{b,i}} \quad P_{0,i} \leq P_{b,i}.
\] (1)

In the second group of indicators, an increase in the quality level of the investigated product \(Q\) leads to a decrease in the value of an estimated absolute quality indicator \(P_{0,i}\) and, accordingly, a decrease in a unit of measurable relative quality indicator \(K_{0,i}\), that is \(K_{0,i} \rightarrow 0\). So, in the second group of indicators of product quality, the basic values of relative quality indicators \(K_{b,i}=0\), and the values of individual relative quality indicators \(K_{0,i}\) should be calculated by the formula:

\[
K_{0,i} = \frac{P_{0,i}-P_{\text{min}}}{P_{\text{max}}-P_{\text{min}}} = \frac{P_{0,i}-P_{b,i}}{P_{\text{i,max}}-P_{b,i}} \quad P_{0,i} \geq P_{b,i}.
\] (2)

Accordingly, the quality profiles of the studied products, formed from unit weighted relative quality indicators, it is advisable to divide into two groups:

- assessed quality profiles \(QP_{K,0}\), formed from unit weighted estimated relative indicators of product quality \(K_{0z,i}, i = 1, 2, ..., n\):

\[
QP_{K,0} = \{K_{0z,1}; K_{0z,2}; ...; K_{0z,n}\}, \quad K_{0z,i} = K_{0,i} \cdot \alpha_i,
\] (3)

where \(\alpha_i\) are the normalized weights of the indicators \(K_{0,i}\) (\(\sum \alpha_i = 1\));

- basic quality profiles \(QP_{K,b}\), formed from unit weighted basic relative indicators of product quality:

\[
QP_{K,b} = \{K_{bz,1}; K_{bz,2}; ...; K_{bz,n}\}, \quad K_{bz,i} = K_{b,i} \cdot \alpha_i,
\] (4)

where \(K_{b,i}\) is the \(i\)-th unit basic relative indicators of product quality, the numerical values of which, as it was noted, in the first group of indicators are equal to one, and in the second to zero.

The basic quality profile is formed from unit weighted basic relative indicators of product quality and is a virtual measure of product quality.

To determine the quality level of the investigated products \(Q\) using a virtual quality measure, i.e., to perform a qualimetric measurement, it is necessary to compare the estimated quality profile \(QP_{K,0}\) of the product under study with the basic quality profile \(QP_{K,b}\), i.e., with a virtual quality measure. To compare the quality profiles \(QP_{K,0}\) and \(QP_{K,b}\) we use the multidimensional scaling technique: one of the sections of mathematical statistics whose subject of study is the processing of data on pairwise similarities, and relations between the analyzed objects in order to represent these objects as points of some multidimensional space [4]. This technique allows comparing the corresponding unit weighted relative estimated \(K_{0z,i}\), and base \(K_{bz,i}\), quality indicators with the subsequent reduction of the scales by which the values of these indicators are determined to a one-dimensional scale for determining the quality level of the studied products \(Q\). The choice of the implementation model of the multidimensional scaling technique is based on the analysis of the presence or absence of a statistical relation (correlation) between individual quality indicators of the investigated products.
In the case of statistically uncorrelated unitary relative assessed quality indicators, to compare the estimated quality profile $QP_{k,0}$ of the product under study with the basic quality profile $QP_{k,b}$, i.e., with a virtual quality measure, we use a weighted Euclidean model of individual differences, according to which we determine the difference between the corresponding unit weighted relative estimated $K_{0z,i}$ and basic $K_{pz,i}$ quality indicators, and the absolute difference between the quality profiles $QP_{k,0}$ and $QP_{k,b}$, i.e. the deviation function $\Delta QP$ between them. There is the following formula:

$$\Delta QP = \sqrt{\sum_{i=1}^{n}(K_{0z,i} - K_{pz,i})^2} = \sqrt{\sum_{i=1}^{n} \alpha_i^2 (K_{0,i} - K_{b,i})^2}. \quad (5)$$

In the case of correlation of the individual relative assessed quality indicators, to determine the level of product quality, we use the trimodal model of multidimensional scaling [4], which allows to take into account the correlation between the unit assessed indicators of product quality $K_{0,i}$ and $K_{0,j}$ ($l \neq j$) and the absolute difference between the quality profiles $QP_{k,0}$ and $QP_{k,b}$, i.e. deviation function $\Delta QP$, determined by the formula:

$$\Delta QP = \sqrt{\sum_{i=1}^{n} \alpha_i^2 (K_{0,i} - K_{b,i})^2 + 2\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \alpha_i \alpha_j (K_{0,i} - K_{b,i}) \cdot (K_{0,j} - K_{b,j}) r_{K_{0,i}K_{0,j}}}. \quad (6)$$

where $\alpha_i$ and $\alpha_j$ are the weighting coefficients of the unit estimated relative product quality indicators $K_{0,i}$ and $K_{0,j}$ ($l \neq j$) respectively; $r_{K_{0,i}K_{0,j}}$ is the correlation coefficient between the values of unit estimated relative indicators of product quality $K_{0,i}$ and $K_{0,j}$.

The values of the correlation coefficients $r_{K_{0,i}K_{0,j}}$ are defined as the ratio of the covariance (covariance moment) $R_{K_{0,i}K_{0,j}}$ of the indicators $K_{0,i}$ and $K_{0,j}$ to the product of estimates of their standard deviations $s_{K_{0,i}}$ and $s_{K_{0,j}}$:

$$r_{K_{0,i}K_{0,j}} = \frac{R_{K_{0,i}K_{0,j}}}{s_{K_{0,i}} s_{K_{0,j}}} = \frac{\sum_{i=1}^{m} (K_{0,i} - \overline{K}_{0,i}) (K_{0,j} - \overline{K}_{0,j})}{\sum_{i=1}^{m} (K_{0,i} - \overline{K}_{0,i})^2 \sum_{j=1}^{m} (K_{0,j} - \overline{K}_{0,j})^2}. \quad (7)$$

where $\overline{K}_{0,i}$ and $\overline{K}_{0,j}$ are the results of measurements of indicators, which with the normal distribution of the results of measurement experiments $K_{0,i}$ and $K_{0,j}$ ($l = 1, 2, ..., m$, $m$ is the number of measurements we calculate as arithmetic mean values of the corresponding samples:

$$\overline{K}_{0,i} = \frac{1}{m} \sum_{i=1}^{m} K_{0,i}, \quad \overline{K}_{0,j} = \frac{1}{m} \sum_{i=1}^{m} K_{0,j}. \quad (8)$$

Thus, in the formulas (5) and (6), the value of the deviation function $\Delta QP$ varies in the range $0 \ldots 1$, and the closer the value of $\Delta QP$ to zero, the closer the values of the estimated indicators $K_{0,i}$ to the base $K_{p,i}$ and the level of product quality is higher.

Based on the values of the deviation function $\Delta QP$ obtained by formulas (5) or (6), we construct a scale for determining the quality level of products $Q$, according to which a higher numerical value corresponds to a higher numerical value of the quality level $Q$:

$$Q = (1 - \Delta QP) \text{ and } Q = (1 - \Delta QP) \times 100\%. \quad (9)$$

Therefore, the value of the product quality level $Q$, determined by the developed methodology, varies in the interval $0 \ldots 1$ or $0 \ldots 100\%$, which is convenient and methodologically justified for use in the practice of assessing product quality (as components of a material circuit flow). In addition to assessing product quality, the proposed methodology, based on the obtained values of the deviation function $\Delta QP$ and product quality level $Q$, allows sorting products by quality level and, accordingly, setting a different price for it (which affects the financial flows generated by the enterprise).

In subsequent works, a methodology for assessing the accuracy of measurements of the level of product quality will be described in more detail. At the same time, it is advisable to evaluate the accuracy
of qualimetric measurements (as a new direction in metrology) on the basis of the concept of uncertainty, which corresponds to modern trends in the development of world metrology and ensures the fulfillment of the uniformity condition for qualimetric measurements.

5. Conclusions
The application of the concept of “qualimetric measurement” in the theory and practice of qualimetry as one of the types of measurements allows for a comprehensive combination of the methodology of qualimetry and metrology, which has powerful scientific, practical, and regulatory tools that allow research in any field of knowledge.

The use of a virtual measure of product quality, formed on the basis of a basic quality profile, allows fully implementing the procedure of qualimetric measurements and determining the measurement result: quality level of the product under study.

The use of the trimodal model of multidimensional scaling allows taking into account the presence of a statistical relation (correlation) between the individual assessed quality indicators of the investigated products and thereby increasing the accuracy of determining the level of product quality.

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