

# System Diagnostics Methods of Regional Sustainability Assessment

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**Abstract**—There is discrepancy between characteristics and properties of Russian regional economies regarded as ecological and economic systems, on the one hand, and strategic planning and management tools of economic development, on the other hand. The issue arises because of misperception of the environmental factor as a deterrent to economic growth. All the above necessitates the improvement to the system of diagnostics methods of assessment of real regional sustainability levels. The plausible application outcome of methods suggested in this paper is adjustment of public structural economic policy and methodological bases for monitoring the results of economic, social, and environmental development to the need of sustainable economy.

**Keywords**—sustainability; system diagnostics; basic indicative approach; structural analysis method; rank analysis method

## I. INTRODUCTION

Adjustment of public strategic planning and management in accordance with the trends and needs of the economy as an ecological and economic system requires updating the interpretation of economic and legal institutions which form the "rules of the game" providing interaction of the state with society and business, as well as adjusting approaches and system diagnostics methods to measure the achieved level of economic stability within a dual interpretation paradigm. The assessment of sustainability, firstly, defines the degree of manageability or control performance of structural changes following the application of the method of structural analysis, based on the ratio of intersectoral proportions of economy; secondly, the level of attainability of environmental and economic security state of the economy, provided that such security is simultaneously a development objective and a system-forming factor of the economy as an environmental and economic system. Institutional factors affecting the economy and the trajectory of its development on the scale of macro- and meso- levels are subjective, determined by historical features and mentality of the population. Most importantly, institutional factors are manageable, amenable to

necessary transformations; that is why correct and reliable diagnostic results are required.

## II. ECONOMY AS AN ECOLOGICAL AND ECONOMIC SYSTEM

### A. Properties and Laws of Development of the Ecological and Economic System

In compliance with H. Spencer's organic Social Evolution Theory, in modern society, the extent of the existing systems' complexity should not be limited to the continuation of the subsystems differentiation, but should include the optimal integration of already existing systems and subsystems appropriate to the needs of the society. This serves as the basis for development and introduction of new system-forming factors and achievement models of the system's stability, as proved by the example of sustainable regional economies and the material of the paper.

Regional economy as an ecological and economic system is a more complex entity which is currently actively developing after the point of bifurcation experienced by many national economies in the past decade. For the ecological and economic system, it is necessary to reduce entropy, since it will grow and accumulate; the output to the environmental level is interpreted as a transition of randomness and uncertainty from one subsystem to another.

Ecological and economic system should be interpreted taking into account its territory, since scale-invariant global approach allows us to apply the ecological and economic system to a lower territorial level. The dependence on the scale of the system is also relevant because of the justification for the illogicality of traditional division of factors affecting the system and its elements into external and internal. Duality inherent to the nature of the ecological and economic system confirms the system paradigm hypothesis about simultaneous existence of exogenous and endogenous systemic definitions that are present in the study. Nevertheless, there may a number of alternative interpretations:

- ontological, gnosiological and methodological interpretations within the triad of semantic approach;
- dual definition of the ecological and economic system within the framework of descriptive and constructive approaches;
- interpretation covering the scope from macro to nanoscale of the system within the framework of the scale-invariant approach, which clearly demonstrates interdependency and interrelation of not only horizontal, but also vertical elements.

Bioeconomic Compatibility (BEC) solves dual problem: firstly, it is possible to decipher the meaning and interrelation with terms used to characterize a sustainable regional economy (balance, symmetry or harmony), showing the achieved level of uniformity (evenness) of the system. Secondly, bioeconomic compatibility is the main condition for ensuring ecological and economic security of the system, and this allows us to build a functional process sequence of the ecological and economic system and effectively manage its development at the regional level. It ensures:

- a) bio-economic compatibility of the elements of the ecological and economic system;
- b) achievement of ecological and economic security of the system and its elements;
- c) consistent and purposeful development of the ecological and economic system.

It is on the example of bioeconomic compatibility that one can conveniently illustrate, define and apply the principle of development of the ecological and economic system as "priorities through parities", the purpose of which is to interpret the conditions for reaching a balance of interests of the sub-elements within ecological and economic system.

Having determined the connection of the term "bioeconomic compatibility" with such terms as "balance", "symmetry" and "harmony", and taking into account the dual nature of ecological economic system, its properties and characteristics under certain operating conditions, we will clarify that such states of the ecological and economic system are purpose of its development. According to system-wide laws by Yu.A. Urmantsev, which include the laws of system asymmetry and symmetry, the development (evolution) of ecological and economic system can be defined as infinitely symmetric, in some respects, and infinitely or deeply asymmetric in others, as it refers to delicate and deeply dialectical process [1].

In the course of systemic diagnostics of the regional economy as an ecological and economic unity it is necessary to determine the system's current stability and complexity of management forms, its state and elements:

- General fundamental sustainability is referred to by Yu.A. Urmantsev as the "C" system's ability to maintain the signs of the "P" system due to the circumstances of the "O" system regarding the changes in the "I" system caused by the "F" factors [2];

- Refined definition divided into 4 (and only 4) classes by Artyukhov describes stability as the "C" system's ability to coincide by the signs of {P} before and after the changes in

{I} caused by the action of the factors {F}. For {P} = const: The first class - {F} =  $\emptyset$ , {I} =  $\emptyset$ . The second class is {F}  $\neq \emptyset$ , {I} =  $\emptyset$ . The third class is {F} =  $\emptyset$ , {I}  $\neq \emptyset$ . The fourth class - {F}  $\neq \emptyset$ , {I}  $\neq \emptyset$  »[3];

- the authors of this paper defines sustainability as a property of the ecological and economic system and the conditions for achieving ecological and economic security: "Stability is the property of the ecological and economic system to coincide in signs {P} before and after the changes of the {I} caused by the {F} factors (external and internal, objective and subjective pyramid factors), as well as the ability to resist negative anthropogenic and other effects on the system elements"[4].

The duality of the term "Risk-free state of the system" is manifested in its interpretation as "state" and the perception of the risk-free state of the system through the triad "norm - transition state - pathology" under the following conditions:

- if the system's state is referred to as the result of the object-system's development determined through the study of the structure, its properties under certain conditions of space and time by certain quantitative and qualitative indicators, then, given the dual nature of the ecological and economic system in which variability and stability, disequilibrium and equilibrium, etc. may occur, the risk-free state of the system represents a result of the development of the ecological and economic system with dominating "normative" structure and diagnostics results.

The system state triad which is relevant for the purpose of system diagnostics, makes it possible to evaluate by comparing the actual and threshold values of the indicators used in the diagnostic methodology: the norm (without the risk of N1 and the acceptable risk of N2); transition state (TS1, TS2 and TS3); pathology (P1, P2 and P3). It is advisable to define the norm as an admissible (ideal) state (or the value of an indicator that measures it) of the system or its elements, in which their functioning is possible and the probability of achieving strategic development goals is high.

If the development is referred to as triad "growth-change-improvement" reflecting economic, social and environmental development results, then the patterns of development characteristic of the ecological and economic system should also be distributed in accordance with this triad.

Based on the characteristics and the laws of ecological development that can be manifested through human activities and without them, as well as social and economic development implemented exclusively through human activities, the authors have determined the laws of sustainable development of the regional economy and the factors that can influence its content and conditions (Table 1).

General patterns of sustainable regional economic development combine social and economic trends in the system's change, taking into account the isomorphism between them. Particular patterns are local in nature and are determined by differences in resource availability, historical retrospect, to which one can include the patterns of development of subsystems of the ecological and economic system or its individual elements. Laws of ecological

development are exemplified by Yu. Odum, L.B. Slobodkina, N.F. Reimers and include about 250 principles, rules, theorems and statements related to the environment as an environment, but not as an ecological subsystem of a sustainable regional economy.

TABLE I. CLASSIFICATION OF REGULARITIES AND PATTERNS OF SUSTAINABLE REGIONAL ECONOMIC DEVELOPMENT

| No/№ | Levels of Classification                                      | Patterns of sustainable Regional Economic Development  |
|------|---|--|
| 1.   | General patterns::  | - spatial patterns of development that ensure or limit economic growth, social changes and environmental improvements in the region;   |
|      |   | - cyclic development defined through the interlacing of cycles of biological evolution, of living organisms and economic development;  |
|      |   | - dominance of ideological (informal) institutions that help to avoid ideological wars due to the predominance of one ideology of co-evolution of ecology and economics;   |
|      |   | - unification of natural and artificial subjects and objects of the ecological economic system by means of dominating the managing principle of "priorities through parities"  |
| 2.   | Individual patterns:  |  |
| 2.1. | Patterns of socio-economic development (SRS) associated with: | - priorities of consumers' behavior (eco-oriented style of the buyer and the triad "motive-interest-behavior" with the dominance of environmental culture and ethics with varying proportionality and peculiarities in the regions of the country);  |
|      |   | - business objectives (parity of economic, social and environmental results of economic activity);   |
|      |   | - economic potential of icertain regions or industries, types of economic activity, capable of ensuring the transformation of state economic policy from the model of the traditional market economy to the model of a sustainable balanced economy; |
| 2.2. | Patterns of ecological development                            | - manifested in the realization of ecological phenomena, processes, relations conditioned by the nature of man as a biological organism, on interests, motives, whose behavior is influenced by the environment.                                     |

### *B. Factor analysis Models of the ecological and economic system*

In the course of the study the authors proved the conventionality of dividing the factors affecting the regional economy as an ecological and economic system, both external and internal due to the inclusion of an ecological subsystem in it. With this in mind, new models of factor analysis have been developed, they contain quantitative and qualitative interpretations of the influence of factors on the state of environmental and economic security and the sustainable development of the regional economy.

Defining the role of environmental and economic security in ensuring sustainable development of the regional economy, consideration of ecological economic factors, their classification and interrelation with environmental and

economic development factors allow the described below classifications and hierarchies of factors to be added to existing theoretical models of factor analysis.

The first proposed model is a six-factor function for analyzing the impact of factors on the state of economic security as an ecological and economic system:

$$Y = f(N_i, k_N, E_i, k_E, C_i, k_C), \quad (1)$$

where  $Y$  is the sustainability level of ecological and economic system;

$N_i$  is the quality of population;

$k_N$  is a coefficient of economic literacy;

$E_i$  refers to the quality of public balanced economic policy (public/ business expenses on environmental protection, innovations and technologies of economic entities);

$k_E$  is the share of renewable resources / technologies in GDP (GRP);

$C_i$  is quality of the natural environment;

$k_C$  refers to the share of territories of ecological well-being [4].

The  $N$  factor includes:

$N_1$  is environmental literacy and ecological ethics at the preschool level;

$N_2$  is environmental literacy and ecological ethics at the secondary school level;

$N_3$  is environmental literacy and ecological ethics at the level of higher education.

Therefore,  $k_N$  can be regarded as a quality factor of population from the point of view of economic sustainability, measured as the proportion of population of the relevant age group with the sufficient ecological knowledge at different levels.

The content of  $E$  factor comprises:

$E_1$  referring to expenses on protection of natural environment;

$E_2$  is costs of preventing negative impacts of economic activity on environment;

$E_3$  referring to costs of environmental innovation / technology.

This classification of costs enables  $k_E$  to be considered as a coefficient of efficiency of environmental costs of state and business as a percentage of GDP (or GRP) for each group of expenses. Gross national income (GNI) is used in the World Bank analysis instead of GDP, therefore alternative calculations are possible.

The environmental quality ( $C$ ) or the quality of the ecological niche of the economy is composed of:

$C_1$  is the magnitude and content of the natural resource potential ( $NRP$ );

$C_2$  is natural and climatic environment suitable for human life;

$C_3$  is natural and climatic environment suitable for economic activities by industries.

In compliance with these factors,  $k_C$  measures effectiveness of interactions between human-and

biosphere. It is expressed by the stability of the magnitude of the natural resource potential (as the coefficient of time variation  $k_{C1}$ ), the share of ecology suitable for human life  $k_{C2}$  (in contrast to the crisis which is in the state of ecological catastrophe based on the results of ecological metrology), the share of a suitable environment for economic activity  $k_{C3}$  (as opposed to a crisis, economically inexpedient or impossible for natural and climatic reasons).

Table 1 presents the result of applying this function to compile a system of indicators that determine the degree of influence of each factor on economic sustainability and security.

TABLE II. SYSTEM OF INDICATORS FOR CALCULATING THE SIX-FACTOR FUNCTION INFLUENCE ON SUSTAINABILITY OF ECONOMY PRESENTED AS AN ECOLOGICAL AND ECONOMIC SYSTE:

| Factors                           | Calculation formula  | Interpretation of results  |
|-----------------------------------|--|--|
| Quality of population             | $k_{Ni} = \frac{S_{Ni}}{S_i},$ <p>where <math>S_{Ni}</math> refers to the population of the corresponding age group with sufficient economic knowledge and literacy<br/> <math>S_i</math> is the total population of the corresponding age group<br/> <math display="block">S_{EES(N)} = \frac{k_{N1} + k_{N2} + k_{N3}}{3}</math></p> | <p>If <math>S_{EES(N)} &lt; 1</math>, a decrease in sustainability is observed<br/>         If <math>S_{EES(N)} = 1</math>, this is the maximum possible level of sustainability</p> |
| Quality of public economic policy | $k_{Ei} = \frac{E_i}{GDP(GRP)};$ $S_{\partial\partial C(E)} = \sum k_{Ei}$   | <p>The bigger the value of <math>S_{EES(E)}</math> is, the higher is the sustainability level ensured by the public environmental policy</p>   |
| Quality of natural environment    | $k_{C1} = \frac{NRP_1}{NRP_0};$ $k_{C2} = \frac{S_{natural\ environment}}{S_{of\ the\ whole\ area}};$ $k_{C3} = \frac{S_{natural\ environment}}{S_{of\ the\ whole\ area}};$ $S_{EES(C)} = (k_{C1} + k_{C2} + k_{C3}) / 3$  | <p>If <math>S_{EES(C)} = 1</math>, sustainability level is decreased<br/>         If <math>S_{EES(C)} = 1</math>, this is the maximum possible level of sustainability</p>           |

The integral index of the  $I_{SEES}$  will be presented as follows:

$$I_{SEES} = \sqrt[3]{S_{EES(N)} \times S_{EES(E)} \times S_{EES(C)}} \quad (2)$$

### III. METHODS OF SYSTEM DIAGNOSTICS AND THEIR IMPROVEMENT PROPOSALS

Среди методов системной диагностики, актуальных для цели оценки устойчивости экономики как эколого-экономической системы, наибольший исследовательский

интерес представляют: индикативный подход к формированию индикаторов оценки состояния безопасности экономики, методы структурного и рангового анализа, позволяющие оценивать устойчивость и результат развития экономик макро- и мезоуровней. Далее представим результаты авторских наработок и предложений:

#### A. Development of the methodology of the indicative approach for the purpose of assessing the sustainability of the ecological and economic system

Among the methods of system diagnostics relevant for the purpose of assessing the stability of the economy as an ecological and economic system, from the perspective of research potential we would like to consider indicative approach to the formation of indicators for assessing the state of the security of the economy, methods of structural and rank analysis that allow assessing the sustainability and the result of the development of macro- and meso-level economies. Let us present the results of the authors' study developments and proposals:

#### A. Development of the indicative methods to assess ecological and economic systems' sustainability

The need to divide the system diagnostics of the stability of the regional economy into "primary" and "secondary" (monitoring) arises from the relationship between the descriptive definition of the ecological and economic system for the purpose of diagnosing it in a static, current state, and in the interrelationship of the constructive definition of the economic system from the environment and interacting with it through "inputs and outputs" for the purpose of dynamic diagnostics of development.

The indicative approach to conducting the diagnostics of environmental and economic security as a system-forming factor of a stable regional economy was assigned to the "primary" diagnosis, conducted to determine the state of the regional economy as an object of management.

On the basis of the research results of the scientific school "Diagnostics and forecasting of economic regional security" (Ural Branch of the RAS Institute of Economics), A.I. Tatarkin, A.A. Kuklin proposed:

1) to transform the "pressure-state-response" model used by the OECD to build sustainable development indicators for the purpose of diagnosing ecological and economic system that allows to determine both the state and development results and the effectiveness of the implementation of concept-strategies-programs for regional management (Figure 1);



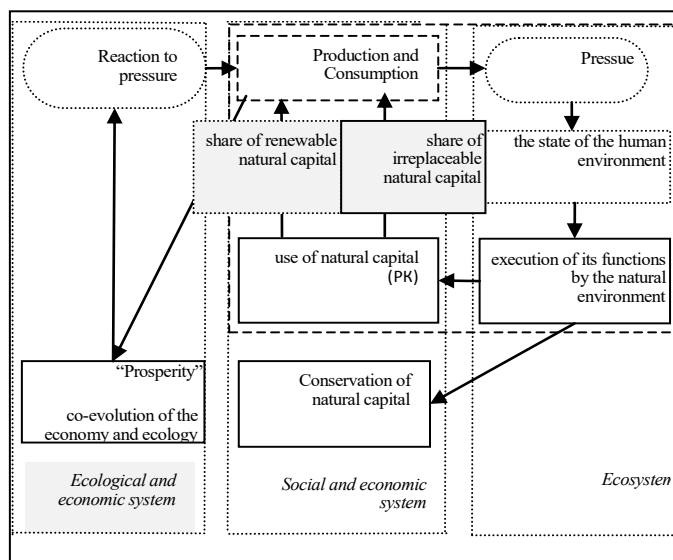


Fig. 1. "Pressure-State-Response" OECD Model transformed into Ecological and economic system Model

2) when determining the stability of the regional economy as an object of diagnosis it is necessary:

- firstly, to identify its composition, number of constituent elements and indicators of diagnostics (indicators) in terms of the structure of the social and economic status and structure of the economy, the degree of its service and industrialization (based on the results of calculating the coordination indicators
- the ratio of the shares of agriculture, production and services in gross added cost;

- secondly, to apply the authors' version of the state security scale of the regional economy as an ecological and economic system, its development is necessary to determine and classify the threshold levels and their normalized values.

The classification of states by indicative parameters on the basis of normalized estimates (the study of the Ural Branch of the Russian Academy of Sciences conducted by A.A. Kuklin, A.F. Shorikov, V.A. Tyulyukin, etc.) was supplemented with the two states of the norm characteristic (Table 3).

TABLE III. CLASSIFICATION OF STATES BY INDICATIVE PARAMETERS

| Security State of the Economic System | Designation | Ratio of normalized and threshold values of indicators   |
|---------------------------------------|-------------|--|
| <i>Norm</i>                           |             |  |
| Risk-free status                      | $N_1$       | Risk-free status of the system / its elements (without admissible concentration limit)<br>$H_{it}^H = H_{H_1, it}$ and $H_{it}^\Phi = H_{H_1, it}$ |
| Permissible risk (for example, MPC)   | $N_2$       | $H_{it}^H = 0$ and $H_{it}^\Phi \neq H_{H_1, it}$  |

$H_{it}^H$  refers to normalized (standardized) value of  $i$  indicator within the acceptable risk for the area in the analyzed period, relative units;

$H_{it}^\Phi$  – stands for actual value of the indicator  $i$  expressed in the system of named units for the  $t$  in the analyzed period;

$H_{H_1, it}$  represents the threshold value of the initial stage of the transition state that goes beyond the permissible risk for the indicator  $i$  of the territory  $t$  in the system of source (named) units.

## B. Content and results of applying the method of Structural Analysis

Taking into account the practice of structural analysis, which is traditionally based on UN indicators (structural shift mass, structural shift index, structural shift rate, structural independence coefficient [5]), the author proposes to consider the alternative approach to the content of structural analysis of the economy using the algorithm for calculating the coordination indices and the subsequent typology of the regional economy for the purpose of monitoring and management [6] (in accordance with the three-sector model of the economy by C. Clark, A. Fischer, J. Furaste).

Aggregated sections  $D_i$  of gross value added (GVA) are formed at the first stage of the developed method of structural analysis:

- $D_A$  agricultural sector share in the GVA;
- $D_i$  industrial sector share in the GVA; including  $D_M$  mining share and  $D_{MA}$  manufacturing activity share in GVA;
- $D_G$  goods production share in the GVA;
- $D_S$  service manufacturing share in the GVA; including share of material services manufacturing  $D_{MS}$  and of non-material services manufacturing sectors  $D_{NS}$  in the GDS.

At the second stage, statistical indicators of coordination  $k_i$ , are calculated; the following variants reflecting the result of the ratio  $D_i$  are possible:

- basic  $k_i$  relating to level 1 of the typology of economic systems:

$$k_\alpha = D_I / D_A; \quad (3)$$

$$k_\beta = D_S / D_G; \quad (4)$$

- additional  $k_i$  relating to the second level of economic systems classification:

$$k_v = D_{MA} / D_M; \quad (5)$$

$$k_\mu = D_{NS} / D_{MS}. \quad (6)$$

If  $k_i$  denominator is 0, then the value of the coordination indicator is equal to the numerator.

The next step is aimed at systematizing the variants of the types of economic development that can be identified and substantiated based on the results of the structural analysis, developed matrix of economic systems types applied according to the presented intersectoral proportions (Table 4).

The calculation of the coordination indicators results in is constructing a graph and the vector of structural changes proper to the studied object (Fig. 2).

TABLE IV. THE MATRIX OF ECONOMIC SYSTEM TYPES BY INTER-SECTORAL PROPORTIONS

| Inter-sectoral proportions<br>(economic development stages) |  | Industrial and commodity META-TYPE<br>by sectors of economy |                                  |                          |                                   |
|---|--|---|----------------------------------|--------------------------|-----------------------------------|
|   |  | $D_A > D_I$<br>(agricultural type)                          | $D_I > D_A$<br>(industrial type) | Including:               |                                   |
|   |  |   |                                  | $D_M > D_{MA}$           | $D_M > D_{MA}$                    |
| Commodity-service META-TYPE<br>by sectors of economy        | $D_G > D_S$<br>(COMMODITY-ORIENTED TYPE) | 1 TYPE - AGRARIAN   | 2 TYPE - INDUSTRIAL              | SUBTYPE - RAW MATERIAL L | SUBTITLE - DEVELOPE D INDUSTRIA L |
|   | $D_S > D_G$<br>(service type)            | 3 TYPE - SERVICE AND AGRARIAN                               | 4 TYPE - SERVICE AND INDUSTRIAL  |                          |                                   |
|   | Including:                               |   |                                  |                          |                                   |
|   | $D_{NS} > D_{MS}$                        |   |                                  |                          |                                   |
|   | $D_{MS} > D_{NS}$                        |   |                                  |                          |                                   |
|   | SUBTITLE - DEVELOPE D SERVICE            |   |                                  |                          |                                   |
|   | SUBTYPE - MATERIAL AND SERVICE           |   |                                  |                          |                                   |

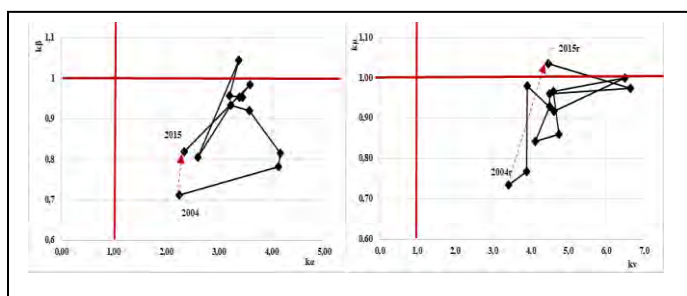


Fig.2. Graphical representation of the ratio  $k_a$  to  $k_\beta$  and  $k_v$  to  $k_\mu$  on the example of the Volgograd region economy in 2004-2015

Tracking the transition of the regional economy from one type (subtype) to another allows one to assess the quality of structural changes and state of structural economic policies implemented at the regional level.

### C. Features of rank distribution of regional economies by effective rank method

For the purpose of correct evaluation of results of territorial assessment at any scale based on the available statistics of social, economic and environmental indicators of the subjects of the Russian Federation, a new approach to the ranking of regions based on the results of development was carried out and tested in foreign publications of the authors [7], [8]:

1) The variation range is calculated:

$$R = x_{\max} - x_{\min}; \quad (7)$$

2) Linear rank distribution is modeled:

$$LRD = x_{\min} + (i - 1) * h \quad (8)$$

where  $i = 1, \dots, n$  is a rank  $r$  of the ranking objects (subjects of the Russian Federation, countries of the world);

$$h = R / (n - 1).$$

3) Isomorphic mapping of the non-linear structure of the index values chosen for the ranking is constructed within the corresponding structure of positive integers:

$$Y = k * r + a_0 \quad (9)$$

where  $Y$  is an indicator of the social and economic development of the territory;

$k$  is the linear coefficient линейный коэффициент;

$r$  refers to the rank of the region;

$a_0$  – is free term.

4) substituting for the previous equation instead of  $Y$  the empirical values of the ranked indicator, and resolving it with respect to rank  $r$ , we get the following determination:

$$r = \text{Целое} \left[ \frac{y - a_0}{k} \right] \quad (10)$$

where *Integer (argument)* is a function that rounds its argument to the nearest smaller integer value.

5) The formula presented in clause 3 is transformed into a formula for calculating the effective rank  $r^*$ , where instead of  $k$  and  $a_0$ , the parameters of the line equation calculated according to linear interval are substituted.

6) The additional procedure for aligning effective rank values for all ranking objects is the shift of the maximum rank to a value of 1.

The consolidated rating is determined by simple summarizing of all calculated ranks. As a result, a full picture of the achieved state is formed due to the implementation of all public measures of strategic territorial management.

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