ENVIRONMENTAL AND ECONOMIC SECURITY OF A REGION: AN INNOVATIVE APPROACH TO MANAGEMENT AND MATHEMATICAL MODELING

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ABSTRACT
In this paper authors present their own interpretation of the category "environmental-economic security", by which is meant the ability of economy to ensure a sustainable economic and social development, at the same time ensuring that the necessary balance can be maintained between economic interests and resource and environmental resistance of ecosystems in different regions, as well as between the scale of economic activity, acceptable risk to the public and the ecological and technological capacity of the territory. The content of environmental and economic security of the region has been defined through a system of functional-structural, subject-object and its parametric representation. It has been found that the system of environmental and economic security of a region is unique and integrated; the authors carried out the typification of this system, defined its goals, objectives and functions. The mathematical model of the system was developed, and the evaluation of its complexity is provided.

Keywords: *mathematical modeling, innovations, innovative approach, economic-mathematic modeling, system of environmental and economic security, region.*

INTRODUCTION

An important condition for ensuring national interests in the field of economy is the transition of Russia and its regions to innovative development, providing a balanced solution of socio-economic problems, and problems of environmental protection in order to meet the needs of present and future generations. This transition requires the formation of a new, ecologically and economically balanced, innovative strategy. The idea of combining security and development turns out to be very fruitful, which opens new methodological horizons for security related studies. Given the above, the economic security problem cannot be addressed in isolation from environmental aspects. This relationship should be based on the results of a comprehensive analysis of the entire set of indicators of social, economic and environmental aspects of society.

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The object of our research is the system of environmental and economic security of the region.

The subject of research includes methodological approaches and the mechanism of ecological and economic security management through economic and mathematical modeling.

The purpose of the study is to develop a methodological basis for the creation of ecological and economic security systems, mechanisms and models of its maintenance in the regions based on the conceptual approach.

LITERATURE REVIEW

In the scientific literature there are many definitions of the system, relating both to the overall system, and to specific systems of various types. They all have an object, a subject, the task, which determines the attitude of the observer to the object and which is the criteria for selecting objects and their properties, the link between the object, the subject and the task [1].

Currently, a particular importance is attached to the evaluation of anthropogenic impact on the ecological situation in the areas where people live. Many reputable scientists determine the human habitat as ecologic and economic system. [2]

The concept of eco-economic system (EES) is widely used in today's economic and environmental literature, along with very similar concepts of "natural economic system" and "bioeconomic system." There are two levels of interpretation of this concept - global and regional. According to the global meaning EES is understood as a special new economic structure of society, a kind of environmentally regulated socio-economic structure, i.e., what is the object and purpose of sustainable development [3].

As early as 1976, Academician M.Y. Lemeshev defined the eco- economic system as "the integration of economy and nature representing interrelated and interdependent functioning of social production and natural processes in the biosphere, in particular" [4].

In this sense, eco-economic system is a territorially restricted part of the technobiosphere where the natural, social and industrial structures and processes are interlinked by mutually supportive flows of matter, energy and information. The concept "technobiosphere" in this case reflects the fact that a part of biosphere undergoes a significant transformation due to the impact of human technical resources in accordance with human socio-economic needs [3].

In our opinion, the main characteristics of eco-economic system should be considered with regard to the system of environmental and economic security of the region, however, they require clarification and specification from the angle of security.

Currently there is no approved concept of "system of environmental and economic security of the region". Basically the concept of "security" is regarded in relation to the security of an enterprise, a state [5-7].

For example, V.P. Mak-Mak considers the enterprise security system as including a scientific theory of safety, security policy and strategy, means and methods of ensuring safety and security concept [5].

V.I. Yarochkin defines security system as an organized set of special bodies, services, tools, techniques and activities that protect enterprises and government vital interests against internal and external threats. [7]

METHODS

The systematic approach to region's security problems; the fundamental works of the classics of economic and life sciences, the works of domestic and foreign scientists, the main provisions of environmental management, national and international experience in the field of economic and mathematical modeling of environmental protection and nature preservation provided the methodological basis for our study.

THE MAIN PART

Description of the system

Economic and mathematical modeling defines the concept of "system" in a more formal manner, freed from substantial characteristics of elements, "relations of order" and links between them.

The process of economic and mathematical modeling is shown in Figure 1

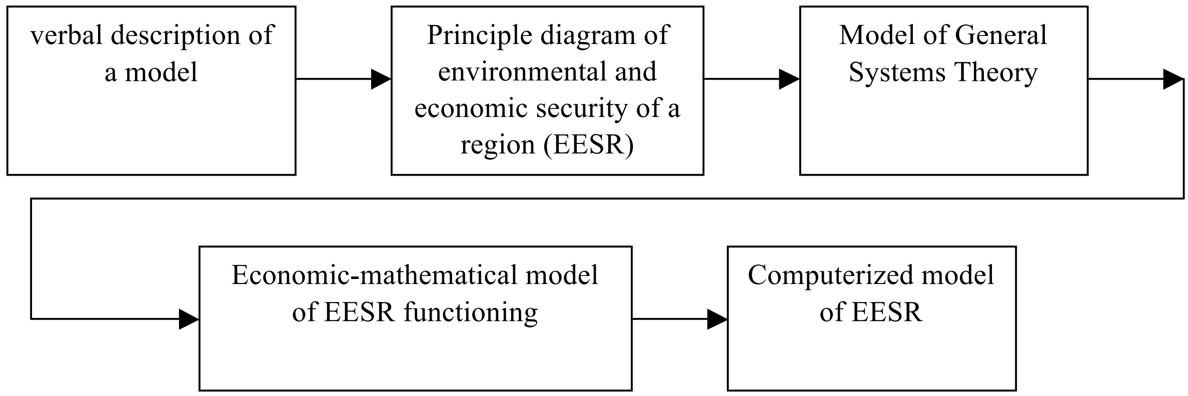

Figure 1. The process of economic-mathematical modeling

Let us use the standard scheme of systems theory [8-12].

We construct generalizing EEBR system model based on the following principles:

1) Basic concepts will be formalized. This means that a precise mathematical definition will be provided to objects under review on the basis of their verbal description, using the minimum necessary mathematical structure in determining their properties.

2) Based on the construction of concepts derived from the formalization, we will develop further mathematical theory for the study of various properties of the system, taking into account the application of the results with practical issues.

Any system can be represented as a set S:

$$S = \{c, K, M\},$$

where c - target vectors; K - set of system elements; M - set of system elements connections.

As stated previously, first, the most basic level of system description represents a set of elements or a diversity of set elements. A diversity of set elements means the totality of objects being constituent parts of the system. The structure of the system means the mode of existence of the system that sets well-identified priorities and relationships between the elements of a system.

The economic and mathematical models of systems and their structures is developed on the basis of a system of elements, its structure and its elements' attributes [11]. The scheme of EECR system model can be represented as shown in Figure 2.

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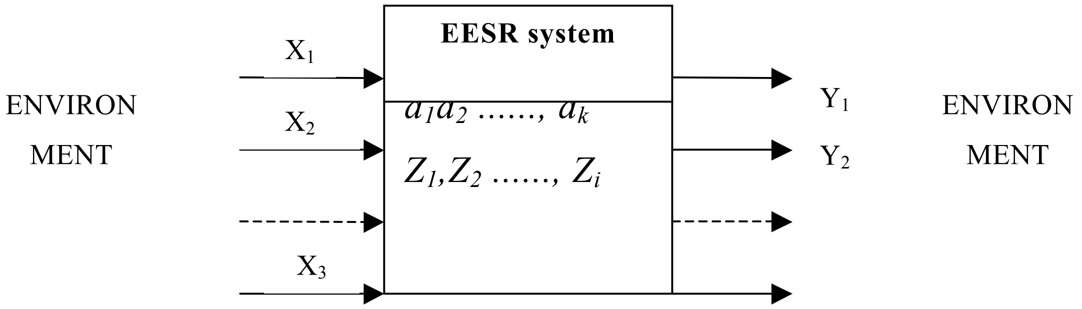

Figure 2. EECR system model

Elements of $X_1, X_2..., X_n$ are called system inputs (input variables), $Y_1, Y_2..., Y_m$ - system outputs (output variables), Z_1, Z_2 ......, Z_i describe the state of the system.

Symbols a_1, a_2 ......,a_k are used for the system parameters. The inputs and outputs of the system communicate with the external environment, i.e., with other systems. The states Z_1, Z_2 ......,Z_i fixate all the changes caused by the arrival of the input signal or due to internal changes in the system.

Let us construct an EECR system model. We use the variables such as: X1- general economic, investment and financial indicators of regional development; X2 indicators of quality of life, poverty and unemployment, demographic; X3 performance use of natural resources, quality of the environment, - as system inputs.

System state is a set of fixed parameter values at a given time, i.e. system characteristics that are important for the purpose of study. Each level of hierarchical structure can contain its own set of current state parameters. These groups of parameters are interlinked, and the general state of the system can be considered as a tree of states [13].

Human activity often results in various disturbing factors, such as pollution of the environment. Anthropogenic factors provoke changes in the state of EECR system, characterized by a set of parameters relevant to this state. There are certain limits of relevant parameters variations, comparison with which allows to form certain relationships: neutral (indifferent) to the extreme concern of the status quo [13].

The states of such a system include:

Z1- high degree of security;

Z2 - acceptable level of security;

Z3 - critical level of security.

System parameters can characterize various rules and regulations, and the threshold criteria for ecological and economic security adopted for any given region.

System outputs display the results of its operation:

Y1- ability of the region's economy to sustainable growth;

Y2- maintaining of an acceptable standard of living;

Y3 - assurance of environmental safety.

Systems inputs, outputs and states are interlinked by functional or statistical dependencies. Setting certain values of input signals, initial parameters, the relationship between the variables, the required indicators are studied using economic and mathematical methods.

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System operation is characterized by the appearance of input, output signals and a change in the state of inputs, outputs and states vector spaces.

The system is in equilibrium if its state can remain unchanged indefinitely. The system may have several equilibrium conditions. It can move from one equilibrium state to another under the influence of the input signals or internal causes.

The system is called stable if the input signal shifts it from one equilibrium state to another. As a rule, all of the systems that are subject to modelling are stable [11].

Assessment of system complexity

The complexity of a system is characterized by a number of sets of relevant parameters (control variables) determining the process [13].
The concept of complexity is one of the most fundamental in the system analysis. System analysis is a research strategy that considers complexity as a significant, inherent property of objects and shows how one can extract valuable information, from the perspective of complex systems. According to Russell Ackoff, simplicity is not set at the beginning of the study, but if you can find it at all, it is in the result of research.

A complex system is a system built to solve multi-purpose problems; a system reflecting different, incomparable aspects of the object; a system, the description of which needs several languages; a system comprising an interconnected complex of different models [14, 15].

The object can be characterized as "complex" if it is related to the system at the level. The objects differ in their complexity. In order to distinguish the complexity of an object, the concept "level of complexity" was introduced. It can be expressed in terms of the amount of diversity, i.e. the number of elements of a particular type, their linkages and "ordering relationships" between them [11].

This approach allows to conclude that every complex object has a certain variety, and the difficulty level is characterized by the number of elements of any nature which are part of the object.

Let us determine the quantity of EECR system variety and estimate its complexity level using N.P. Buslenko's approach [12].

As it has been defined above, EESR consists of three security subsystems (k_1) - ecological, economic and social, each of them including at least four components (k_2). All subsystems elements interact with security objects (k_3), which conditionally include 9 elements (Fig. 3). Thus, there are three types of elements, i.e. n = 3.

For each element of i-type system, i = 1,2, ... n, we set the weighting factor S_i, characterizing the complexity of this element and chosen empirically based on the fact that economic component is the leading element in EESR.

We shall define that element of the first type (economic component) has a weighting factor $S_1 = 50$, the element of second type (environmental component) $S_2 = 25$, the element of third type (social component) $S_3 = 25$. Thus, the overall sum is 100.

Then the quantity of system variety without considering the links will be:

$$S = \sum_{i=1}^{n} S_i k_i ,$$

where k_i is the number of i-type elements in the system.

$$S = 50*3+25*12+25*9=675.$$

The total number of system elements N is determined by the formula, and is 24 (3 + 12 + 9):

$$N = \sum_{i=1}^{n} k_i .$$

The structure of EESR system determines six types of links, reflecting the relevant processes:

- socio-economic links in the industrial sector;

– environmental links in ecosystems;

– economic-environmental links: the environmental impact on the production process;

– environmental-economic links: impact of economic activities on the environment and natural resources;

– social- environmental links: impact of the quality of environment on human health and living conditions;

- environmental-social links: human impact on the natural environment.–

We calculate the amount of diversity, taking into account the possible links and using the following formula:

$$S^* = (1 + y * \alpha) * S,$$

where y is a coefficient reflecting the diversity of links, compared with the complexity of the elements; a is the factor of links realized in the system.

Given that not all links are realized in the system, a is set to 0.91 (a = 0.91) and y = 9, then

$$S^* = (1 + 0{,}91 * 9) *675 = 6178.$$

Thus, the complexity of the system is defined as follows: without considering the links between elements of the system, the quantity of varieties in the system is S = 675, and taking into account the actual relationships S * = 6178, as S *> S, then the system is complex.

If we increase the number of conditionally atomic parts of the system, making them smaller, then, of course, the number of "ordering relationships" and links will increase, as well as the system diversity or the level of complexity of the object.

Management of the system

There are two concepts of management: management as an administrative activity and management as a process. Economic-mathematical modeling of EESR system can use both.

Management as an administrative activity is present in the eco-economic systems. The regulatory function in environmental and economic security at the regional level is manifested in the authorities' actions to neutralize threats detected in the course of monitoring. As a result, an effective set of management measures is carried out to get out of high-risk zones.

But these bodies or subsystems of subjects base their activities on a fundamentally different categories and therefore cannot be completely formalized in the form of economic and mathematical models.

Since the management is in general difficult to be formalized, and the use of specific mathematical techniques is possible only for objects having a specific, predetermined objectives of the operation,

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the system EESR being targeted, we will understand the EESR system management as the process, focusing it on achieving certain goals.

Thus, management is the process of formation and implementation of deliberate action on the object-system, based on the exchange of information between subject and object of management. [11]

Management as a process is considered regardless of the specific characteristics of object and subject, it allows to manage the object without the complete knowledge of it. In this sense, the management as administrative activity is a broader concept than the management as a process.

Thus, when using economic and mathematical modeling, the management has to be considered as process control.

If management is used to refer to a process of deliberate action on the object in order to ensure its effective and stable operation and development, EESR management can be defined as a process of fulfillment of continuous interlinked successive actions (control functions) targeted on ensuring EESR.

The model of EESR system, able to generate and correct its objectives, can be represented as a conventional system with additional controlling inputs, or actions (Fig. 3).

At the same time, the controlling action is a deliberate informational influence on the system having resource and organizational support. [13]

The control inputs g1, g2, ... gp are intended for changing system objectives, which may occur only in the external environment for this system.

External environment is an area outside of internal system control effect, i.e. an area out of control of the decision-maker. [13]

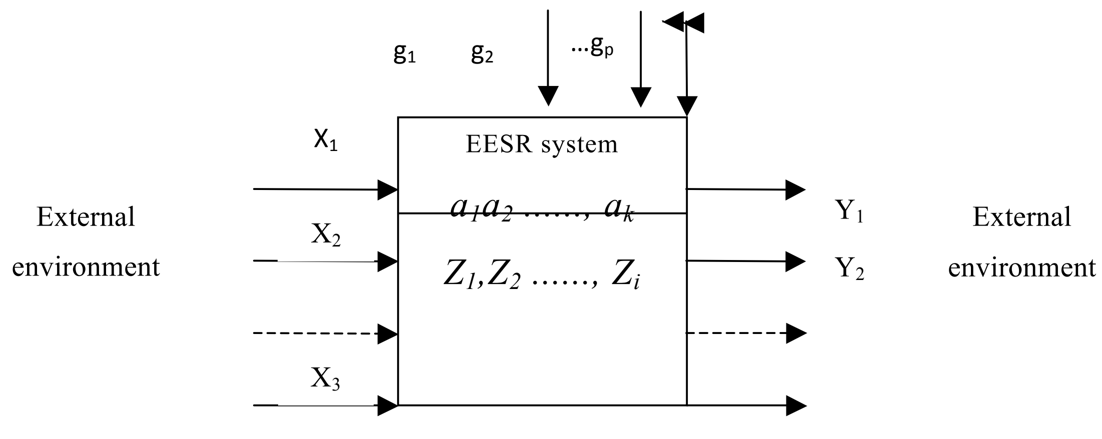

Figure 3. Model of a system with adjustable objectives

The central concept of controlling system is "information", i.e. instrument influencing the system operation without regard to the material composition of this instrument [14].

Any management of such systems is carried out as informational process: acquisition, processing and transmission of information. The status of the system changes due to the information (input signal), being a response to the command, which is generated in the system after analyzing the information contained in the input signal

The management of a system is inextricably linked to the concept of the purpose of system management or simply to the purpose of the system. The purpose of the system means the desired outputs, provided that the outputs reflect the status of the system. In modelling, the purpose of the system appears as an objective function.

The concept of the purpose of the system is an idealized concept. Typically, the output signals or system statuses are close to the target values or fluctuate around them. To assess the approximation to the purpose of the system, the concept "criterion of purpose" has been introduced.

The criterion of purpose includes the rule allowing to evaluate the actual behavior of the system (inputs state, objective function value) in comparison with required behavior and record the sufficiency or insufficiency of this evaluation. The criterion of purpose permits to select system behavior (optimum alternative), most corresponding to the value of the purpose of system.

Let us consider the basic provisions of the definition of the objective functions of systems.

The principle of unambiguousness requires the existence of unique objective function for the system.

The principle of appropriate form consists in establishing a form of the objective function that would have a practical sense, i.e, specify extremality, certain interval, any other performance requirements and would be single-valued.

The main principle should be EESR adaptive management based on feedback, monitoring the changes of system status and thus its response to controlling action [13].

The goal state should be structured in an appropriate manner, i.e., an integrated set of relatively simple and reliable parameters (target indicators), - or rather their deviations from the target values, showing the distance from the target. At first stages of the cycle of ensuring environmental and economic security, when intermediate target states are implemented, the role of government environmental control will be very significant, if not decisive. Then, as the economy and people's consciousness become greener, the trend of self-regulation will increase in ensuring environmental safety. [13]

The objective function of EESR system can be represented as an objective function of process quality in a quadratic form:

$$F = \Sigma\Psi_j\,(\hat{Y}_j - Y_j)^2,$$

where Ψ_j is the positive weight ratio of j- parameter; $\hat{Y}_j$ is the reqired value of j- security parameter; Y_j is the actual value of the j security parameter.

The objective function can be specified for each model element, taking into account the criterion of its achievement.

The fundamental concept of feedback is at the heart of most of the management processes. The models similar to EESR system realize the control information based on feedback information. [16]

The formal notion of feedback from the perspective of the system means obtaining of information on the management outputs. The output signal of the system, carrying information on its status, must be received at the system input. The feedback in EESR system can be negative and positive.

Negative feedback is characterized by the fact that the output signal acting on the input of the system has the opposite sign to the input that caused the change of the system status.

Due to the action of negative feedback mechanism that extinguishes disturbances always present in the system, and don't let them grow to devastating critical size, the system's ability to resist to the processes of destruction and remain in the field of sustainability is obtained. Positive feedback means that the output signal supplied as feedback to the input, has the same sign with the input signal and

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amplifies the input signal action. Systems with positive feedback are unstable and are always at stages of development or death. Loss of system stability and its destruction are defined by the action of positive feedback characterized by a snowballing disturbances increase.

In this case, management process consists of two interconnected steps: development of a program that defines the required behavior of the controlled object; establishment of a mechanism that regulates the implementation of the program (the price system, including payments for environmental pollution and payment for environment "services"). [16]

The object of management in eco-economic system is extremely complex and continually varies over time. Managing of such object must be able to adaptation to the ever-changing characteristics of the controlled object. The management system, capable to perform this task, must have a set of well-developed backward and forward linkages with the controlled object and cannot operate as a fixed program with only one feedback loop [13].

Adaptive management is also a feedback control, and unlike the latter is characterized by the presence of specific adaptive mechanism that accumulates and analyzes information about earlier situations and generates new behavior based on experience and in accordance with the specified objectives and criteria. Adaptive management is inherent in complex systems, that change the behavior strategies and programs in the course of their operation [11].

The conclusion could be made that the management system of environmental and economic security of the region should have the properties of an adaptable and constantly improved system. Its objectives, structure, tools, directions, forms and operating methods should be modified in accordance with changes in the internal and external environment, providing an acceptable status of economic security of the region at any given time [18-22].

The quality of system management should be considered in terms of its effectiveness and sustainability. Efficiency is the achievement of an objective taking into account given criteria. [11]

Let's consider the concept of system sustainability. All organizational systems have the common goal: self-preservation. The system tends to the stable state of dynamic equilibrium, which corresponds to the region of stability. [13]

The stability of the system will be considered as the system's ability to move from one equilibrium state to another in case of exposure to the external or internal changes [11].

The concept of stability is related to the magnitude of the impact, or the signal that caused the change in the system state. Therefore, speaking on the stability of the system, the limit deviations of input signal or internal changes in the system should be taken into account and compared with the change in the system state. If X denotes the input signals, then for a stable system the following is true:

$$\text{at } X_{min} \leq X \leq X_{max} \text{ values } Z_{min} \leq Z \leq Z_{max};$$

and for unstable systems:

$$\text{at } X_{min} > X > X_{max} \text{ values } Z_{min} > Z > Z_{max};$$

where X_{min}, X_{max} are respectively minimum and maximum possible changes of input signal or internal state of the system; Z_{min}, Z_{max} are respectively minimum and maximum possible changes in the systems state not beyond the system stability region.

If Z denotes the state of the system, then, the values, i.e. ΔZ and ΔZ^{+}, ie, $\Delta Z^{-} = Z_{min} - Z$ and $\Delta Z^{+} = Z_{max} - Z$, are called the margin of system stability.

If there are several parameters of the system state, stability conditions must be fulfilled for each component of states $Z = (Z_1, Z_2, \ldots, Z_n)$, $i = 1,2,\ldots n$. If at least one value of Z_i does not meet stability conditions, the system is unstable as a whole. Stable transient behavior is characteristic to stable systems.

Selecting values Zmini Zmax is very essential for the quality of management, as it affects the stability of the system, but it is quite complicated and can only be carried out by experts on a particular object or process with the help of expert analysis.

Selecting Z_{min} and Z_{max} values is essential for the quality of management, as this affects the stability of the system, but the choice is quite complicated and can only be made by experts on a particular object or process with the help of expert analysis.

Reliability and efficiency of the system

The reliability of a system have a direct impact on the quality of its management. Complex systems, such as EESR, typically have many replicated or substitutional attributes, so the failure of one element cannot affect the performance or stability of the system, but the failure of unreplicated attributes can result in decreased efficiency of the system or even its destruction.

The general model for evaluating the reliability of the system can be represented as follows. Let us denote the quality of management by W. Let's assume that it is expressed in terms of two main characteristics: system efficiency E and the stability of the system U, i.e.:

$$W=\varphi(Э,U, \Theta),$$

where φ is functional which links E, U and Θ; Θ - indicator of system reliability.

In this case, the change in the indicator of system reliability will affect the quality of system management. Both performance indicators, i.e. the achievement of the system objectives, and system stability indicators, i.e., stability factors, could be affected. Changes in system efficiency, including its reduction can be expressed as follows:

$\Delta E = Eo- Eн$,

where ΔE is the change in performance indicator; E - efficiency of the system (objective function value) within a predetermined error in the case of absence of failure of the system attributes; CN - the value of objective function of the system in case of failure of any system attributes.

The value of E should be specified for each individual type of system.

It is impossible to calculate the efficiency of E for complex systems in theory, therefore, to evaluate the reliability of a system under the influence of external factors or failures of some attributes of the system is possible using simulating models.

Self-organization of a system

Studying EESR as a dynamic system, attention should be paid to the property of self-organization of dynamic systems, i.e. to their ability to rebuild their structure or behavior to compensate disturbances or modify them, to adapt to environmental conditions [17].

A wide range of studies focuses on the properties of self-organizing systems. The intuitive understanding of this comes down to the ability of an object to change its behavior or structure depending on the environment in accordance with the interests of the object [11].

Discovery of self-organization mechanisms allows to develop a fundamentally new rules of relationship with natural systems. The typical features of self-organizing systems include the following [17]:

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1. Self-organizing systems have the ability to change the characteristics of their parameters, their functional relationships structures in accordance with the changing external conditions in an optimal manner.

2. Functioning of self-organizing systems is aimed at increasing the productivity of labor (and product quality), while reducing consumption of energy and resources.

3. The dynamics of self-organizing systems is difficult to predict in detail and over the long term. However, no matter how varied the conditions are, the functional processes in their development are always focused on self-preservation, self-reproduction, entropy reduction.

4. The self-organizing systems purpose that they must achieve cannot be set proactively and exactly.

5. In the context of limited resources and at equal initial parameters, the interaction of self-organizing genetically homogeneous and peer-to-peer systems predetermines the transition of one system or more to a hierarchically higher rank. Moreover, the entropy of the system is reduced by increasing it in other systems.

The problems of self-organization of social and economic processes and the problem of balanced, sustainable development are so closely connected that grow into each other.

In a formalized representation the property of self-organization can be described as follows [11]. Let's assume that we have a system (EESR) which may be represented in the form of a complex system model with additional control inputs G = g1, g2, ..., gi (see Fig. 4). There is also a system EESR *, the model of which generates values of control signals g_1,g_2,, …, g_i, depending on the value of the system management quality indicator W, i.e.

$$G=\Psi(W,\lambda),$$

where G is a set of control input signals that can adjust the value of the management quality W depending on the set of rules λ; Ψ is the functional linking the dependence between W and λ.

Sets of rules λ and their relationship with quality of management W generates a control signal to the G input, and can be set only by experts.

The control signal G adjusts the value of management quality index W, which, in turn, can lead to a desirable change in the system parameters a1a2 …ak.

Figure 4 shows th emodel of the object as a model of a complex system, which has the property of self-organization.

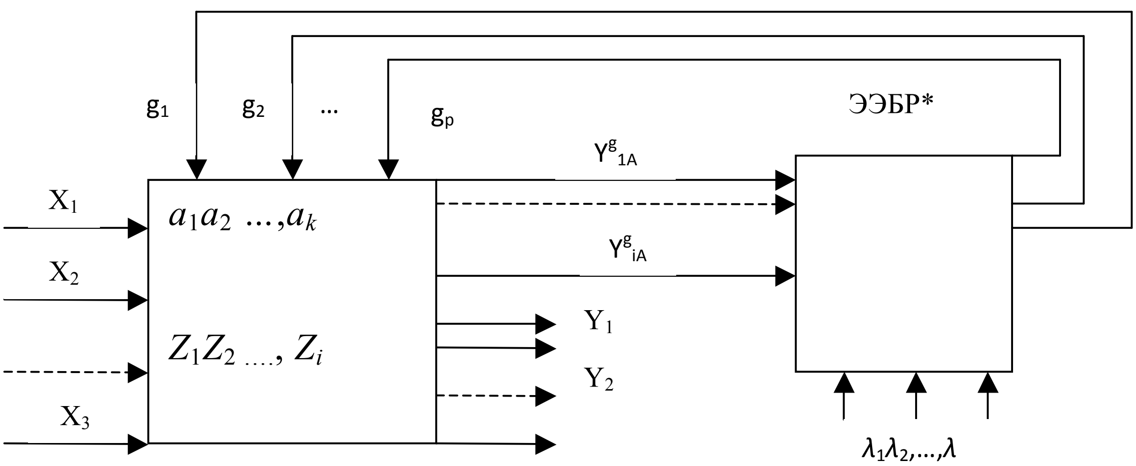

Figure 4. Model of self-organizing object

Simulation of self-organizing systems does not raise any major theoretical problems, if it is possible to enter any set of rules λ1, λ2, ..., λ adjusting W. In this case, these rules can be presented by security thresholds. Inputs, outputs and status of this model (X, Y and Z respectively) operate normally and describe an object or a process. The outputs of the system with the index «g», i.e. Yg,, display management quality parameters W. They come in EESR system *, where they are analyzed in accordance with the existing set of rules λ1λ2, ..., λ and generate control signals G.

Depending on the set of rules, the self-organizing systems are divided into adaptive, homeostatic and extreme systems. EESR is an adaptive system, since it can improve its behavior depending on the state values for a certain period of time, i.e., at the beginning, in the middle or end of the interval during which the state of the system is measured.

CONCLUSION

The following conclusion can be drawn on the issue:

1. The system of environmental and economic security differs in its structure from the system of economic security both in the number of relationships and their quality characteristics.

2. The dynamics of environmental and economic security structure increases dramatically due to the deepening and widening of relationships of its elements as a result of continuous development of its most active - economic - sub -system.

3. Innovative management in environmental and economic security in a region can be ensured by the implementation of a unified organizational system with properties of adaptation to the changing characteristics of the controlled object and functioning on the basis of a well-developed system of feedbacks.

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