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CONCEPTUAL BASES, PRINCIPLES AND SCENARIOS OF THE MODELLING OF ENVIRONMENTAL SAFETY IN THE SYSTEM OF SUSTAINABLE DEVELOPMENT

Introduction

A society and a state are regarded safe when implementing a model of balanced development, and are dangerous when ignoring it. The survival of humanity in general and each state in particular requires a systemic safe transition to a model of balanced development and harmonious life.

The model of harmonious coexistence of society and nature and achievement of balanced development on its main social, economic and ecological components implies, to our mind, observance of the following principles as to the creation of a model for the institutionalization of environmental safety [Danilishin and others, 2008].

- *Information sufficiency.* If complete information about the system is absent, it is impossible to construct a model; and if it is redundant, it is impractical. There is some critical level of a priori information (informational sufficiency), which makes it possible to develop an adequate model.
- *Expediency*. The model assumes the achievement of goals that are defined at the initial stage of the formulation of the problem of the modelling.
- *Feasibility.* The model promotes realization of the research goal with allowance for marginal resources with probability which is essentially different from zero and for a certain time. Some limit value P (degree of risk) of probability of achieving the goal of the modelling $P(t)$ is usually specified, as well as the actual time limit t to achieve the goal.
- *Multiplicity of models.* The emerging model should reflect, first of all, those properties of the real system (or phenomena) that affect the chosen efficiency indicator. Accordingly, during its use, certain components of reality are determined, which makes it possible to examine the process from different aspects and in more detail.

- *Aggregation.* A complex system preferably contains units (subsystems), the adequate formal consideration of which is promoted by standard mathematical schemes. The principle of aggregation makes it possible to flexibly rebuild the model depending on the research tasks.
- *Parametrization.* In a number of cases, the modelled system includes some relatively isolated components that are characterized by appropriate parameters, including vector ones. They can be replaced by numerical values, rather than describe the process of their functioning. If necessary, the dependence of the values of such indicators on the situation can be presented in the form of tables, graphs or analytical expressions (formulas), for example, using regression analysis. The parametrization principle allows one to reduce the amount and duration of the modelling, but possible decrease in the adequacy of the model should be taken into account.

The detailed analysis of the results of the research is given below. The need for the modelling arises both at the stage of the systems design when analyzing the effectiveness of the taken decisions and the exploitation – to evaluate the consequences of introducing changes into the system. In this case, at different stages of design (technical or work project) with specification of the initial data and discovery of new significant factors, the degree of the detailed elaboration of the process increases, which should be reflected in the model. Consequently, the latter can simultaneously include blocks with varying degrees of detailed elaboration, which model the same components. That is, it is necessary to apply the methodology of the integration multilevel modelling.

At the same time, due to the lack of the established theoretical-methodological and methodical basis, the modelling of environmental safety does not meet modern needs. In particular, the impact of the institutions of safety guarantee, the role of investment activities on improving the environmental situation are smoothed over. Time and space factors are ignored.

The main objective of the study is to model environmental safety of sustainable development on the basis of the existing conceptual bases and principles of overcoming threats and risks.

The paper is organized as follows. Section 1 is devoted to the empirical background and study of the features of the simulation of sustainable development security. Section 2 presents the results of security modeling based on the time and factor approach. Its includes the research methodology, the results of its application and interpretation. Conclusions summarize the research and contain some recommendations for theory, practice, and future research on the topic.

1. Literature review

The chosen problems, including the individual aspects of the manifestations of safety, the principles of the modelling processes were studied in the works of Bystriakov I., Varnalii Z., Danylyshyn B., Małgorzata Sej-Kolasa and others [Bystriakov and others, 2012; Burkaltseva, 2012; Varnaliy, 2005; Danilishin and others, 2008; Małgorzata Sej-Kolasa, 2009]. An important aspect in the development of conceptual bases, principles and scenarios of the modelling in the system of sustainable development is the study of perspective schemes of the corresponding design, the theory and methodology of institutional changes, the fundamental theoretical foundations, which are considered in the works of Veblen T., Campbell J., North D. others [Veblen, 1984; Campbell, 2004; North, 1990].

In the light of the above-mentioned problems and the established principles of the modern institutional model, we single out nine basic aspects of environmental safety: *artificiality*, *complexity*, *durability*, *structural stability*, *quantifiability*, *targeting*, *manageability*, *thoroughness* and *duality*, which in different combinations and with the corresponding priority predetermine its genesis and management actions [Danilishin and others, 2008; Burkov and others, 2009; Yerina, 2001].

Symmetrical characteristic of danger complements thoroughness of safety. The danger, in general, corresponds to «insecurity» – due to different circumstances and conditions – the existence of a society in the desired state and a certain system or its subsystem (natural, technogenic, fire-explosive danger, dangerous geological and hydrological phenomena, etc.). The peculiarity is that safety and danger, in contrast to risk, operate in the same functional plane, the first relates to the desired, the second – to the real state of things.

The modelling of safety based on the structure and synergistic properties of a functioning entity (system) of safety management of social natural systems (SNS) and its relevant methods, which, in accordance with the risk analysis methodology at its macro- and micro-levels of functioning, requires a number of tasks to be solved, namely:

- Creation of scenario matrices (information models) of possible states of a set of technological systems in the corresponding SNS (the same structure for different specific technological systems).

- Aggregation of the set (system) of technological systems into a separate generalizing indicator of their combined action, which is an external load on the geoecosystem.
- Estimation of the potential capability (norm) of the geoecosystem to take the external load of technological systems.
- Analysis of possible crisis (catastrophic) failures of the geoecosystem under the existing load on it.
- Representation of a set of possible failures of the geoecosystem as a scenario matrix (information model), its behavior in the management of the natural and anthropogenic safety of the SNS.
- Development of a scenario for a possible development of SNS in general (its macroscenario) as a necessary informational context for the management of natural and anthropogenic safety in the region.

The first five tasks are informationally united by two common features. First, they contain both spatial (on the basis of geographic fields) [Armand, 1988, p. 95–99] information of the mutual positioning of technological systems and geoecosystem and scalar information about the corresponding modelling «curtailment» of spatial data in separate numbers that are necessary for specific calculations. Since there are no precise methods for converting spatial information into scalar and vice versa, therefore, individual heuristic approaches are used. Secondly, these tasks, in contrast to the deterministic and statistical, relate to synergistic objects and processes capable of self-organization in space and time, exhibiting non-standard properties that are important in modelling. They include:

- *Non-linearity of behaviour* [Danilishin and others, 2008]. Most technological systems and geoecosystems are characterized by such states that can vary (appear, exist and disappear) in many equal ways. A new state often occurs as a result of a sudden growth of minor normal fluctuations together with additional, even small, external influences that cause negative (emergency, catastrophic, crisis) changes in systems.
- *Attractor equilibrium* [Dorohuncov, Ralcuk, 2006]. Geoecological and technological systems are characterized by such type of unstable equilibrium that as a result of a violation is replaced by a new state as an implemented variant from the list of alternatives that existed before. These possible new states activate (attract) processes of self-organization in systems and are implemented in the conditions of the corresponding, even insignificant, influences in the direction of a certain attractor.

- *Instability near peaks*. In the process of state change there appear certain disadvantages in technological systems and geoecosystem. In particular, the continuity of smooth changes in their parameters under the influence of insignificant control pulses or random disturbances may be violated suddenly and unevenly. Most of these processes have an unexpected crisis or catastrophic nature and are mathematically specified by the ruptures in the surfaces of the development of their states.
- *Resonance excitation.* Ways (discrete set) of self-organization of the states of the technological system and the geoecosystem are usually activated with the achievement of one of the specific state-attractors by impulses of external influence. The activity of the latter is due to the fact that their spatial configuration corresponds to the configuration of the own structure of the system.
- *Modes of crisis (catastrophic) functioning*. There are three modes of self--organization of states of geoecological and technological systems. The most common is the so-called *HS*-mode (in synergy terminology) – from the base center of the crisis act there is a divergence, the dissipation of the negative influence with the penetration into the space that did not belong to its sphere of influence. S-mode has a significant scale of manifestations; its effect is limited to the space, structure of the system. LS-regime concerning the capture, localization of the crisis phenomenon in the modelling and management of natural and anthropogenic safety, acts as an exception in the restricted zone.
- *«Soft» character of the technological and geoecological systems.* The peculiarity of these systems is that they are difficult to be determined in a completely unambiguous way by their structure and parameters; they are within the range of permissible values. This inaccuracy (blurriness in determining the geoecosystem) of systems depends on the objective (individual system-forming components cannot be precisely defined in space and time of their action) and subjective reasons (fuzzy, quantitatively-qualitative, poorly structured process).

At the microlevel of the management of the natural and anthropogenic safety of technological and geoecological systems, appropriate solutions should be open to possible adjustments in case of inconsistencies between the system models that they relate to and their actual state, similar to the scenario matrices, open to the information update [Dorohuncov, Ralcuk, 2001, p. 75-77].

It should be noted that such properties are manifested at the microlevel of the management of natural and anthropogenic safety, that is, specific technological and geoecosystems, and are expressed by the «codes» of fast variables of synergetics, where impulses and manifestations of risk take a key position. At the same time, at the macrolevel of safety management – SNS in general – behaviour is reflected in the «codes» of slow variables of synergetics and characteristics of the safety proper. Thus, there is a certain gap between the macro- and microlevels in the description and management of SNS. It can be overcome if the desired result is attained and on the basis of adequate methods. As a result, it is necessary to provide a common approach to the description of the SNS both at the microlevel of determining states, behaviour of technological and geoecosystems, and at the macrolevel of SNS characteristics from the standpoint of safety. The above should be reflected in the scenario matrices of SNS systems – their risk characteristics will correspond to this, which are both the initial information for the adoption of relevant management decisions. The methods to overcome the gap should take into account the individual characteristics of the technological and geoecological system. There are two of its main directions: an analytical--expert one, using a reliable reasoning device, based on the generalization of experience, analogies and induction; model-synergetic – dynamic computer modelling of the synergetic features of these systems with the «reproduction» of a large number of possible situations. The second direction is more correct and at the same time more complex, although both are effective in «converting» the risk characteristics into the necessary safety management decisions and, conversely, can complement each other [Yerina, 2001].

A key feature of the structure of the scenario matrices of technological and geoecological systems is that negative states develop as a rule not continuously, but discretely, which corresponds to instability near peaks, that is, in their critical state (Fig. 1).

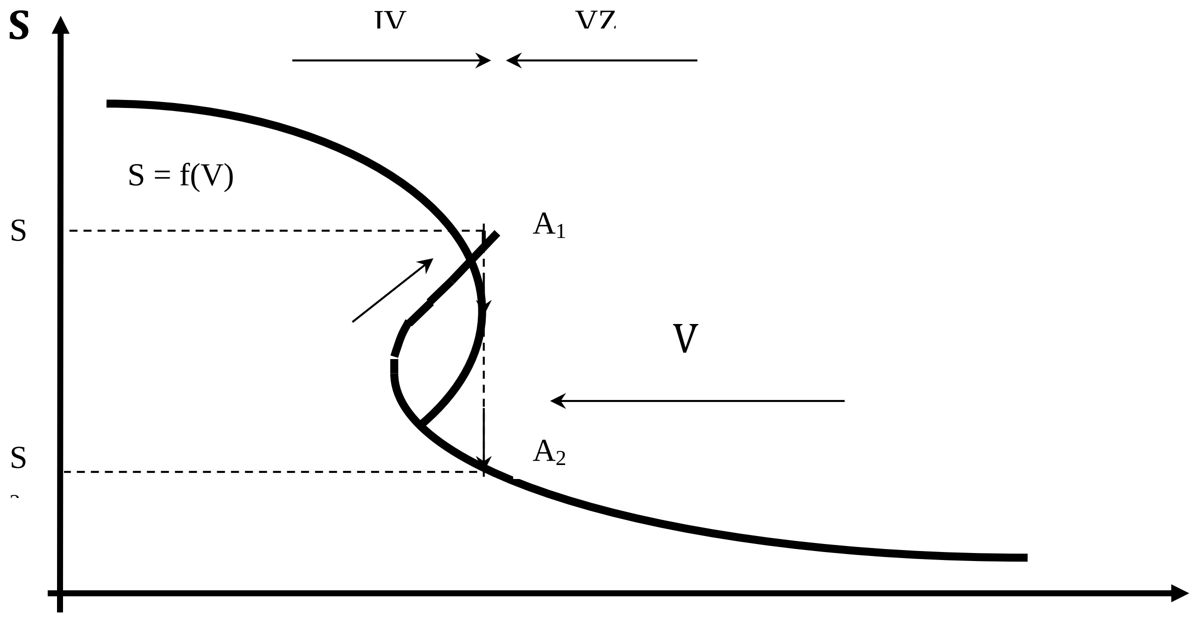

Fig. 1. Scheme of formation of the states of possible equilibrium of the object (system) in the process of safety management (Danilishin and others, 2008)

Macrolevel safety management in the region is based on a macro-scenario for the possible development of this SNS, which performs two functions in the management and research of safety. First, it specifies, in fact, the dynamics, the vector of changes on the corresponding horizon of estimates of the future in the time interval {*tp*, *tz*} – the initial and final evaluation period. Secondly, it unites technological, geoecological and socio-economic systems through their scenario matrices. Therefore, in the managerial vision of the future, the basis of the macro-scenario is not extrapolation-inertial, but a «breakthrough», heuristic definition of the probable space of possible states of SNS on the basis of «if – then», in which, in other circumstances, its state as an object of management must be specified accordingly. In another sense, the macro-scenario in the management of natural and anthropogenic safety, SNS is relatively to it a certain «external information shell» of a plausible representation of a set of exogenous inputs for the model of SNS indicators, reacting to which it will change its state, gaining new characteristics of its capabilities.

2. Scenarios of the modelling of environmental safety in the system of sustainable development

2.1. Research methodology

Safety modelling, taking into account institutional transformations (or responses), characterizes the level of response to challenges, taking into account the analysis of environmental safety issues in the system of sustainable development, the state of legal mechanisms, the fight against threats and risks, etc. However, institutional indicators are difficult to quantify. Thus, D. Burkaltseva [Burkaltseva, 2012] suggests that this category should consider the level of corruption and the shadow economy, emphasizing their significance in the process of qualitative assessment of economic security. According to other definitions [Khvesyk, Holian, 2007; Ivashina, 2009; Ostrom, 2005], institutional indicators are the nature of changes in ownership forms in the economic complex, the role of small enterprises in economic development and social shifts. Considering the institutional transformations in environmental safety and taking into account the peculiarities of the study of ecological and natural and anthropogenic safety, it is worth emphasizing their decisive influence on the ecological competitiveness of the territory. This indicator, as already mentioned, is vulnerable to any organizational and economic transformation that reflects the level of competition in the environment.

In the process of modelling, two aspects of the econometric model should be taken into account: theoretical, qualitative analysis of interconnections and empirical information. The theoretical information is reflected in the specification of the model, which is an analytical form of the econometric model. It has one or more functions used to construct models and probability characteristics. We have chosen an econometric model in order to parametrize the effects of external and internal dangerous factors on the institutional component and environmental safety of the territory.

The choice of the analytical form of the econometric model should take into consideration the list of specific factors, that is, their selection for econometric modelling is necessary. In the course of such research, repeated return to the stage of the specification of the model, specification of the list of factors used, and the type of dependence when the function and its components do not correspond to the actual processes, which indicates the false specification, may be possible. There are the following types of them:

- ignoring individual factors while developing an econometric model;
- use of a factor that is not important for measurable connection;
- inappropriate forms of dependence.

The choice of an acceptable form of dependence is based on the degree of consistency between the type of function and the input data of observance. The adequacy of the model can be determined by analyzing the residues.

Based on the results of the calculations of ecological competitiveness level of Ukraine and its regions in 2005, 2008-2010 and 2015 [Khvesyk, 2014), econometric (economic-

-mathematical based on quantitative relationships construction between indicators of the actual statistics) modelling of environmental safety is proposed, which is based on two separate approaches.

The model of the period determines the dependence of the ecological competitiveness of the region on the level of environmental hazard (component by component), innovation and investment activities in the region, aimed at improving the state of the environment. It is:

$$EC = f\ (INAH_t, IAAH_t, IWH_t, IHLFR_t, IWM_t, IEC),$$

where EC – ecological competitiveness of the region;

$INAH_t$ – index of natural and anthropogenic hazard of the region;

$IAAH_t$ – index of atmospheric air hazard;

IWH_t – index of water hazard;

$IHLFR_t$ – index of hazard of land and forest resources;

IWM_t – index of waste management;

IEC – index of economic costs for environmental protection in separate time periods (t = 2005, ..., 2015...).

2.2. Research results

The modelling results are based on a modified stochastic approach, which, in addition to the actual, includes additional (conditional) information that quantitatively reflects the peculiarities typical of such processes (Table 1).

Table 1

Time safety model*

Year	Determination coefficient	Constant	Regression coefficient				
			IAAH	IWH	IHLFR	IWM	IEC
2005	0,628	0,089	-1,233	-0,009	-0,282	0,631	0,756
2008	0,688	0,075	-3,906	-0,656	-2,669	1,192	0,498
2009	0,554	0,166	-2,537	-0,015	-2,127	-0,280	0,842
2010	0,897	0,103	-0,773	-1,218	-0,981	0,348	0,752
2015	0,735	0,059	-4,819	-1,368	-1,557	-0,046	0,567

** Source: calculated by the authors.*

The statistical characteristics of the model are within the limits of the relevant probability criteria, the determination coefficient – from 0,554 in 2009 (the worst model by the causative effects) to 0,897 in 2010 (the most effective).

The model of change in content and structure is based on statistical variables over the period under study. The modelling is also based on a modified stochastic approach which is combined with an assessment of the impact on the factor of the competitiveness of the risk factors, takes into account their quantitative effect and the nature of their impact (Table 2).

Table 2

Factor safety model*

Dependence variants	Regression coefficients						Determination coefficient
EC= *f* (*t*)	-0,012						0,233
EC = *f* (INAH,*t*)	5,182						0,891
EC = *f* (IAAH,*t*)	1,739						0,564
EC = *f* (IWH,*t*)	1,739						0,364
EC = *f* (IHLFR,*t*)	2,082						0,650
EC = *f* (IWM,*t*)	8,758						0,769
EC = *f* (IEC,*t*)	3,430						0,816
EC= *f* (INAH, IAAH, IWH, IHLFR, IWM, IEC)	INAH	IAAH	IWH	IHLFR	IWM	IEC	0,735
	-0,965	-0,780	-0,516	-0,605	0,490	1,003	

* *Source: calculated by the authors.*

This model consists of three components:

- The dependence of EC = *f(t)*, where the competitiveness is related to the factor of time as a numerical index. It is determined by a very low determination coefficient (0.233), which indicates practical absence of a condition of EC time, and its competitiveness is mainly formed by genetic factors (confirmed by the data of the second component).
- The dependencies of the EC = *f*(INAH,*t*), EC = *f*(IAAH,*t*), EC = *f*(IWH,*t*), EC = *f*(IHLFR,*t*), EC = *f*(IWM,*t*) and EC = *f*(IEC,*t)*, where the state of the EC is consistently combined with the corresponding variable genetic and temporal factors. This component demonstrates the apparent increase in the condition of the EC by its factors, primarily genetic. As for the dependance EC = f (t) with the determination coefficient 0.233, the situation is somewhat different. In the second component of the model, its minimum value is higher and is 0.364, and the maximum ones are 0.891

and 0.816. It should be noted that INAH and IEC almost equally affect the competitiveness of the territory

- Parametric (as direct management dependence) model combining EC with its six genetic factors. It most accurately reflects the dependence of EC on the latter, quantifying the positive impact on the territory of the index of waste management and economic expenditures. We note the negative influence of other factors (due to the specified specificity) and a high level of their causative actions (determination coefficient – 0,735). Such models are open and vulnerable to any external manifestations. The list of relevant factors may be changed, and the expansion of the dynamic range will enable the determination coefficient to be specified.

Conclusion

Thus, the conceptual bases, principles and scenarios proposed by the authors allowed carrying out modelling of environmental safety in the system of sustainable development. First of all, this was possible due to the methodology developed in previous works on the formation of ecological competitiveness as part of the transformational processes introduced to improve the region's ability to compete with others in the context of sustainable development safety and to further assimilate the anthropogenic impact of production. It is important to emphasize that the conceptual scheme of the formation of a system of indicators of competitiveness, taking into account the safety factors proposed by the authors, included ecological, natural, technological indicators and indicators of the development of social (in the interaction of the social environment and the economic environment) and economic (capital investments, expenditures on environmental protection measures, GRP, etc.) subsystems. Therefore, it can be argued that time and factor safety models take into account all factors of influence as much as possible.

The proposed modern model of institutionalization of environmental safety, based on the principles of information adequacy, feasibility, expediency, aggregation and parametrization allowed us to analyze the non-standard properties of existing models due to its nonlinear behavior, attracting equilibrium, unstable nature near the peaks, the modes of crisis functioning at the macro-, meso- and microlevels. The econometric model of the period and change in the dependence of the ecological competitiveness of the territory on the level of environmental hazard (component by component: $INAH_t$, $IAAH_t$, IWH_t, $IHLFR_t$, IWM_t, IEC), innovation and investment activity, is aimed at improving the state of the environment. As a result, the obtained modelling results based on a modified stochastic approach, using real information that quantitatively reflects the peculiarities of the processes of influence, have proved a significant influence of genetic factors on ecological competitiveness.

Further theoretical, methodological and applied studies in this area are carried out within the framework of scientific research works on the themes: "Environmental modernization in the system of natural and anthropogenic and environmental safety of Ukraine" (SR № 0114U005281, 2015-2016), "State ecological policy of Ukraine in the conditions of decentralization of power (SR № 0114U005282, 2015-2016)", "Natural--technogenic and environmental safety in the conditions of economic transformations in Ukraine" (SR № 0116U007938, 2017-2018).

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Abstract. *The scientific study is devoted to the development of conceptual bases, principles and scenario of the modelling of environmental safety in the system of sustainable development. The study considers artificiality, structural instability, quantifiability and duality of environmental safety. Factor and time components of safety determined according to the modified stochastic approach are also disclosed. They interpret the dependence of the environmental competitiveness of the region on the level of environmental hazard (component by component), innovation and investment activity aimed at improving the state of the environment. The authors of the paper argue that safety modelling, in view of institutional transformations (or responses), characterizes the level of response to challenges, taking into account the analysis of environmental safety issues in the system of sustainable development, the state of legal mechanisms, the struggle against threats and risks, etc. In the light of the aforementioned, an econometric model of the period and change in the dependence of the ecological competitiveness of the territory on the level of environmental hazard, innovation and investment activities aimed at improving the state of the environment is developed. The obtained results of the modelling, based on modified stochastic approach using real information that quantitatively reflects the features of such processes, prove a significant influence of genetic factors on competitiveness.*

Keywords: *safety modelling, sustainable development, scenario approach, environmental safety, institutionalization, ecological competitiveness*