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## INTEGRATING MODEL FOR SUSTAINABLE DEVELOPMENT

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**Keywords:** integration model, sustainable development, economic-mathematical model, socio-ecological-economic system.

*The article presents the integration model of sustainable development as a family of models for creation of integrated information systems of ecological economic and socio-humanitarian management of different socio-organizational systems and especially economic objects of technogenic character for ensuring the sustainable and viable development. The problem of sustainable development for the "hexagon" of main assets (capitals), supporting the vital activity of socio-ecological-economic systems is considered and defined: the concept of sustainable development, the system of sustainable development global dimensions, and the level of sustainable development.*

**Introduction.** Current issue of ecological, economic and socio-humanitarian, safety and sustainable development of civilization has come to the forefront of scientific research and public consciousness in general. Humanity came to the limit when modern civilization often the so-called — technologically and consumer, revealed its hopelessness, when it is necessary to seriously reconsider its foundation in a serious way and consciously choose another spiritual and ecological development strategy, otherwise the humanity can be estimated from Earth because of global systemic crises that have erupted in recent years. To solve this problem, humanity must abandon a number of stereotypes and direct the vector of civilizational development to the formation of the sphere of mind ("noosphere" according to V.I. Vernadskiy). The formation of noosphere ecological imperative is associated with the formation of such a society that is capable of ensuring the coevolutionary and viable development of civilization for planetary integrity. Sustainable and safety development is impossible without spiritual, cultural and educational improvement by the person himself. The new model of civilizational development, which implements non-traditional environmental, economic and demographic imperatives, should have a deeply humanistic social orientation. Such an approach to understanding the noosphere requires the creation of a new model of science, which should

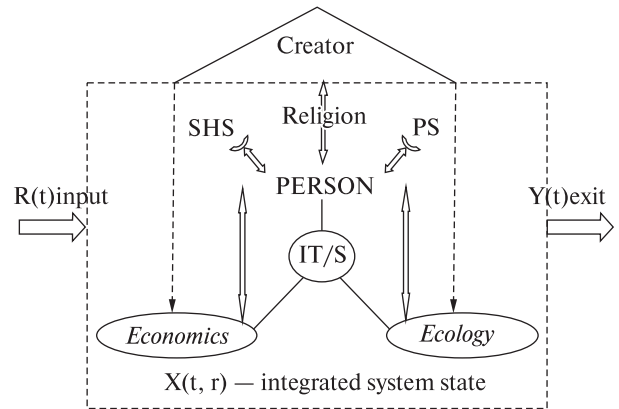
be based not only on a rational-intellectual approach to the consideration of ecosystem, but also to rely on its spiritual and cultural components. If the mechanism of activity optimization while moving to the noosphere is the mind, then spiritual and moral criteria are evaluative characteristics of it, since spirituality is opposite to the material and natural factor and not rational or irrational [1, 4, 11].

At the same time, the most important problem is the integration of science, education and technology based on the noosphere paradigm of sustainable development.

Why do we need integration? In the whole humanity history, the history of Eurasian space countries, there were many different crises, conflicts, wars, cataclysms that threatened the existence of life on Earth. However, each time, humanity found the strength to unite intellectual, material and spiritual capabilities, which ensured the preservation and development of life on Earth in all sorts of evocations. Today the world is once again in a global crisis, and the integration of opportunities is again required.

Why, above all, the integration of science, education and technology is necessary? Because of this integration, we get an answer to the question "How?" to preserve the development of humanity in the conditions of diverse and multidimensional external (space), internal and hybrid threats. The answer to the question "How?" will presupposes the existence of a developed system of measurement (measures) combining science, education and technology. The fundamental rules for integrating the values of science, education and technology are: a) harmonization: science — education — technologies are integrated and form a complete system, if proportionality of their basic principles and laws is ensured by eliminating gaps in dimension; b) innovation; c) fundamental nature: the use of fundamental knowledge and the results of the noosphere paradigm of sustainable development.

All world scientific schools have the aim to preserve Earth for the future generations. However, to achieve this goal, they offer different methods. For example, the western school offered the control of population growth (the strategy of the "golden billion"), the eastern school offered the observance of dogmas (the strategy of Eternal life), and the Russian school offered the transition to the noosphere, i.e. strategy of noosphere sustainable development.



**Fig. 1.** An integrated model of sustainable development of global system (society, world civilization)

An innovative model of sustainable and safety development of societies and the world as a whole should be built because of an integral paradigm of socio-ecological-economic unity and socio-humanitarian technologies. The following system as "Creator — Man — Socio-humanitarian-ecological-economic environment" is the object for system analysis studying, synthesis, innovative technologies of modeling and management. At the same time, a global goal to ensure the safe existence and sustainable development of the entire world civilization is the research and development of integral models of the entire system with the following orientation structure (Fig. 1).

Here SHS — Socio — humanitarian system; PS — political system; IT/S — innovative technologies and synthesis;  $R(t)$  — input effects on the system (resources, specified regulatory functions, conditions, time and other restrictions);  $Y(t)$  is the integral output of the system (both "useful" and "harmful").

The concept of sustainable and safety development implies a change of the traditional economy paradigms, the humanization and ecologization of its main principles, the search for common approaches and the consistency of concepts for the development of ecological and socio-economic systems. During recent years, a new interdisciplinary field of applied science has emerged it is an ecological economics. Ecological economics is a new field of research that deals with the relationship between natural ecosystems and socioeconomic systems in the broadest sense, relationships that are crucial for many current problems of humanity, as well as for building a sustainable and high-quality future.

Therefore, in the current conditions of instability and crises, the problem of developing methods

and technologies of analysis, modeling, forecasting and decision-making for the sustainable development of viable socio and economic systems becomes even more urgent. These systems are characterized by complexity of structure and behavior, synergetics, nonlinearity, and have other "NO" and "MANY" characteristics factor and features [1, 4].

Moreover, a very important problem is also the study of systems with integral properties, that is, systems that include socio and ecological economics and humanitarian subsystems (SEEGS) as systems of the future (noosphere type systems) in their structure. Local regional production systems such as technogenic industrial systems (TIS) are also SEEGS type systems.

Traditionally the methods and models of management and decision-making that are based on the object approach are traditionally used to investigate and solve these problems. Recently, however, a number of scientific publications and scientific schools have emerged, focusing on the importance and necessity of accounting for the dynamics of the subject's behavior, the use of a subject-oriented and reflexive approach [10, 11].

This article proposes the models and technologies for managing the viable and sustainable development of the TPP of the region as a SEEGS-type system based on an integrated object and subject oriented approach. The conceptual model, a generalized synergistic model of dynamics with uncertainty (stochastic and chaotic factors), as well as a variant of a nonlinear dynamic model of subject behavior of management and decision-making, the decision-maker person (DMP), etc., are offered.

In the conditions of future transition of society to the sixth, and especially to the seventh technological ways of development, when creating the integral models and technologies, it is essential and important to take into account the socio-humanitarian fact, reflective and subject-oriented approaches, etc.

**The purpose of article** is the following: to show the importance and necessity of ecological economics and socio-humanitarian micro and macro models development integral that based on the modern theories and analysis problems of modeling, forecasting and management of ecological economics, social-humanitarian systems and technologies, taking into account the instabilities to ensure safety and sustainable functioning and development, to offer some concrete results.

**Material of the main results.** An overview and analysis of some obtained results in recent years by various authors on macro and micro modeling of dynamics of ecological economics and socio-humanitarian systems and processes that function and develop in complex conditions of nonlinearities, instabilities and crises are proposed. A brief description of the results with the necessary sources for detailed reading was provided [1–14]. The author hopes that this material will be useful for well-known specialists of researchers in this field of science, and for young scientists also.

1. The conceptual model of integral ecological economics, socially-humanitarian development and management of a complex system in the conditions of uncertainty, instability, complexity and the like "NO-factors" and "MANY-factors" can be represented in the form of a theoretical-multiple tuple of the form [1, 4, 11]:

$$IS := \langle E_c, E_n, S_o, H_u \rangle; \\ \langle X_1, Y_1, F_1, G_1, K_1, \Omega_1 \rangle, \\ R_1, U_1, E_1, T \rangle \quad (1)$$

where  $\langle E_c, E_n, S_o, H_u \rangle$  — integral tuple of the basic set of systems, moreover  $E_c$  — economy (economic system);  $E_n$  — environment (eco-sphere);  $S_o$  — social sphere (social system);  $H_u$  — humanitarian components in the model. The tuple consists of well-known components for each of the above systems.  $R_1 = \langle R_c, R_n, I_n, \tau_{II}, R_S \dots \rangle$  — a tuple of resources,  $R_c$  and  $R_n$  — economic and environmental resources;  $I_n$  — investments;  $\tau_{II}$  — information and innovation potentials;  $R_S$  — a resource to ensure security against a range of threats, risks and crises.

The general scheme of sustainable and socio-humanitarian development integral model of global (world) system, which the authors call the noosphere model of development, can be represented as an integrator:  $S = E_n \oplus E_c \oplus S_o \oplus H_u$  — an integral "4-unit" system in which the subsystems:  $E_c$  — economic system,  $E_n$  — ecological system,  $S_o$  — social system,  $H_u$  — humanitarian system;  $X(t, r)$  — state of the integral system  $S$ ; in the space of variables  $(t, r) \in [T \times R^3]$ ;  $X_0$  — state of the system  $S$  at the initial moment of time  $t_0$ ;  $W$  — set of disturbing environmental factors.

The generalized diagram of an integral system is a "four-headed" integrated noosphere model of system development is a socio-humanitarian and ecological economics system, with components (sub-

systems): 1—economy, 2—ecology, 3—social sphere, 4—humanitarian sphere, as well as the corresponding synergistic properties: 1.2 — "Viability" (ecological-economic), 1.3 — "Justice" (socially-oriented), 1.4 — "Cultural", 2.3 — "Acceptance-bridge" (socio-ecological), 2.4 — Humanitarian and ecological, 3.4 — Socio-humanitarian. The finer properties of the integrated system, such as 1.2—1.4, 1.2—2.3, 2.3—3.4 and 1.4—3.4 and others, require further examination, analysis and determination (Fig. 2).

Thus, the system (model) of sustainable development is the integration of 1 + 2 + 3, and the NMSD can be called as the noosphere model of sustainable development ("civilization model") and defined as a set (1.4—1.2), (1.2—2.3), (2.3—3.4), (1.4—3.4), which defines a system with integral properties.

2. The conceptual model of forecasting and control of ecological economics processes (EEP) of technogenic object in the conditions of "NO" and "MANY" factors existence can be represented in the form of a theoretical-multiple model as a tuple:  $\langle X, Y, F, H, R, E, \Omega, T, G, K_u, K_p, P, U \rangle$ , where  $X$  — the set of possible states of technogenic economic object (TEO);  $Y = \langle Y^{ecn}, Y^{ecl} \rangle$  — total output of technogenic economics object, and  $Y^{ecn}$  — a productive set (useful output), and  $Y^{ecl}$  — a set of pollution (harmful output);  $F = \langle F^{ecn}, F^{ecl} \rangle$  — a model display of feasibility study;  $H = \langle H^{ecn}, H^{ecl} \rangle$  — general observation operator (measurements);  $R$  — resource set (the main controlled input of feasibility study);  $E$  — the set of indeterminate factors (both external and internal, both additive and multiplicative), in particular, this is a set of stochastic, fuzzy, multiple or mixed non-definitions;  $\Omega$  — many restrictions;  $T$  — time interval of feasibility and development of feasibility TEO study;  $G$  — target set;  $K_u$  — a generalized ecological and economic management criterion (ECE);  $K_p$  — generalized criterion for forecasting optimization (CFO);  $P$  — ecological and economic forecasting operator (predictor);  $U = \langle U^{ecn}, U^{ecl} \rangle$  — vector of ecologic and economic management (EEM). The terms "ecn" and "ecl" correspond to economic and environmental variables.

The aim of optimal ecological and economic forecasting, predictor definition, both for internal and external processes, can be formulated as follows: to determine the estimation of  $\hat{x}(t_k + \delta)$ ,  $\delta = \delta_0, \delta_1, \dots$  state vector  $x(t_k + \delta)$  at a predetermined forecast step on the basis of multiple ecological and eco-

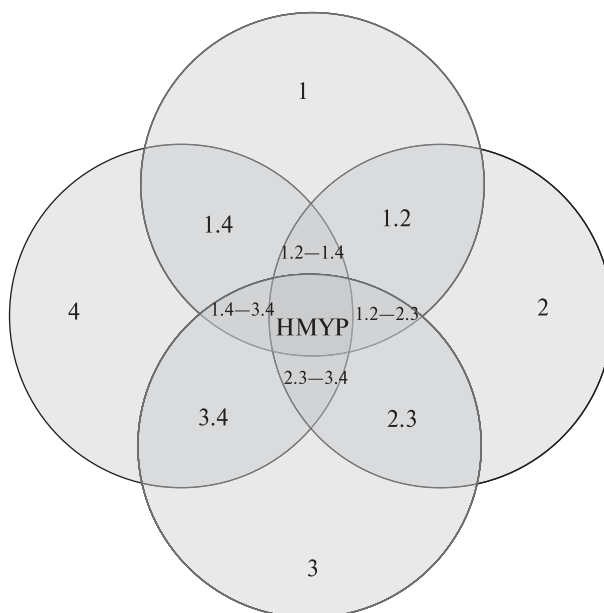


Fig. 2. Diagram of "4 single" integrated development system

nomical observations  $\{y(t), t \in [t_0, t_k]\}$  and according to a given CPC  $K_p$ .

The task of EES is to determine the effective integral control vector  $U = \langle U^{ecn}, U^{ecl} \rangle$  based on estimates  $\hat{x}(t_k + \delta)$ ,  $\delta = \delta_0, \delta_1, \dots$  and a nonlinear dynamic ecological and economic model of TEO that achieves  $G$  under the given generalized ecological and economic criteria  $K_u$  and constraints  $\Omega$ , taking into account uncertainty and risk conditions.

The multiplicative additive stochastic model with the chaotic dynamics in the general form can be represented as vector equations:

$$\dot{x} = A(t)x(t)[X^0 - x(t)] + D(t),$$

$$A(t) = a(t)\lambda(t)\zeta(t), \quad D(t) = d(t)\xi(t)$$

or, a multiplicative additive stochastic model with the chaotic dynamics and control, i.e. subject to the impact management:

$$\dot{x} = A(t)x(t)[X^0 - x(t)] + D(t) + P(t),$$

$$A(t) = a(t)\lambda(t)\zeta(t), \quad D(t) = d(t)\xi(t),$$

$$P(t) = p(t)\psi(t)u(t).$$

The observation model is represented:

$$y(t) = H(t)x(t) + \eta(t). \tag{4}$$

The following notation is used here:  $\xi(t), \zeta(t), \eta(t)$  — multiplication additive stochastic components in models (2)—(4),  $\lambda(t)$  — chaotic compo-

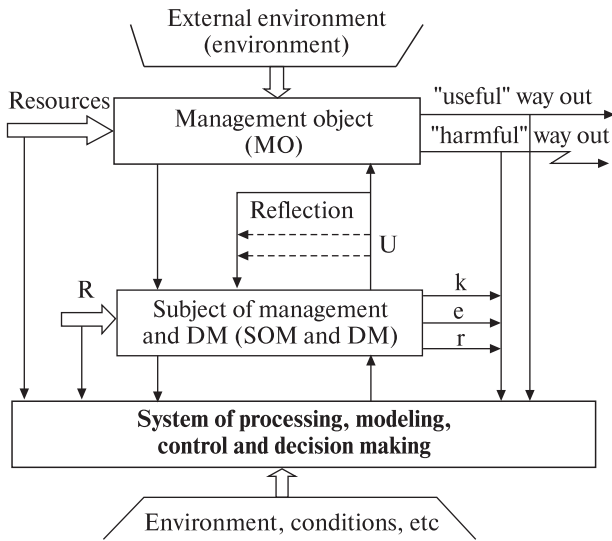


Fig. 3. Diagram of object- and subject-oriented management and DM

ment in the model of system (2). The remaining notations are given above.

3. The integral socio-ecological economics dynamic model of behavior with spiritual and moral variables can be conceptually represented, in the general (in block) form:

$$\begin{cases} \dot{X}_1 = f_1(X_1, X_2, X_3, X_4; P_1, \xi_1), \\ \dot{X}_2 = f_2(X_1, X_2, X_3, X_4; P_2, \xi_2), \\ \dot{X}_3 = f_3(X_1, X_2, X_3, X_4; P_3, \xi_3), \\ \dot{X}_4 = f_4(X_1, X_2, X_3, X_4; P_4, \xi_4), \end{cases} \quad (5)$$

where  $X = (X_1, X_2, X_3, X_4)$  is the combined vector of behavioral variables and states of socio-ecological economics system, taking into account the variable level of spirituality (SEESD) —  $X_4$ , and in (5)  $X_1 = X_1(t)$  — the vector of economic variables;  $X_2 = X_2(t)$  — the vector of environmental variables (pollution variables);  $X_3 = X_3(t)$  — the vector of social variables;  $P = (P_1, P_2, P_3, P_4)$  — the cumulative vector of SEESD parameters (internal and external environment);  $\Xi = (\xi_1, \xi_2, \xi_3, \xi_4)$  — the vector of external random and indefinite variables. For example, for TPS [1, 11]  $X_1 = (K_1, L_1, I, \tau, C)$ ,  $C = (C_1, C_2, C_3, C_4)$  — the vector of some parameters of consumption (costs), and  $C_1$  — the value of social consumption (wages, etc.),  $C_2 = C_e$  — consumption for the environment,  $C_3 = C_s$  — consumption for safety,  $C_4 = C_i$  — volume of investments for innovative, information and humanitarian technologies.

A generalized diagram of an integrated hierarchical object- and subject-oriented control system and DM is presented in Fig. 3.

Subject-oriented management and decision-making (SOM and DM) in Fig. 3 is presented in the block “Control subject and DM”, where  $k, e, r$  are the corresponding modes,  $k$ -cognitive variables,  $e$ -emotional-psychological variables,  $r$ -reflexive variables, which together determine the dynamics of persons behavior who is a decision maker.

4. A synergistic model of nonlinear dynamics of integral stochastic system with the chaotic behavior in a generalized form can be represented as:

$$\begin{aligned} \dot{x}_i &= \left[ \lambda_i \xi_i(t) x_i(t) \left[ \Sigma_X \pm \sum_{j=1}^n a_{ij}(t) \prod_{k=1}^j x_k(t) \right] + \right. \\ &+ \left. \sum_{l=1}^3 d_{il} \frac{\partial^2 x_i}{\partial r_l^2} + w_i \right] + b_i u_i(t), \\ i &= \overline{1, n}, \quad \overline{x}_i(0) = x_{i0}, \end{aligned}$$

where  $\langle \xi_i, w_i \rangle$  are the stochastic perturbing components of model;  $\{a_{ij}(t)\}$  — non-stationary components of model;  $\{d_{ij}\}$  — diffusion coefficients that determine the level of state variables distribution;  $\Sigma_X$  — total maximum (maximum allowable) value of vector  $X$ ;  $\{\lambda_i\}$  — a set of parameters that lead to randomness.

In particular, this model can also be represented as a system of equations:

$$\begin{aligned} \partial X_i / \partial t &= A_i [\xi_i (r_i X_i - \sum_{j \neq i} b_{ij} X_i X_j - a_i X_i^2) + \\ &+ D_i(x, y) \nabla X_i] + \zeta_i + u_i, \end{aligned}$$

where  $X_i$  — coordinates of the system state vector, and  $X_i = X_i(t, x, y)$ ;  $i, j = 1, 2, \dots, n$ ;  $r_i$  — coefficient of reproduction (reproduction, growth, development, etc.);  $a_i$  — saturation parameter limiting growth (reproduction);  $b_{ij}$  — parameter of interaction between subsystems (subjects of economic activity);  $D_i(x, y)$  — diffusion coefficient of the  $i$  — subsystem (economic entity) at a point  $(x, y)$ ;  $\xi_i \equiv \xi_i(t, x, y)$  and  $\zeta_i \equiv \zeta_i(t, x, y)$  — stochastic multiplicative and additive components of model, respectively;  $u_i \equiv u_i(t, x, y)$  — the coordinates of control vector, management decisions;  $A_i$  — scaling factor,  $\nabla$  — the Laplacian, i.e.  $\nabla(*) = \partial^2(*) / \partial x^2 + \partial^2(*) / \partial y^2$ ,  $t \in [0, T]$  is the time interval for the system functioning and development [1, 4].

Such models describe and encompass a broad class of complex processes and systems to which NMSD relate.

5. Modeling of ecological and economics dynamics of development management of technogenic system in the conditions of uncertainties and risks (variants of general formulation). The problem of technogenic economic system control (TES) as a super-complex dynamic nonlinear system with the aim of translating it into a state of socially and ecologically oriented economic system (SSEOES) is urgent [1, 4].

Let be  $x(t) = (x_1(t), \dots, x_n(t))$  — a phase vector of macroeconomic (or socio-economic) variables (parameters) that describes the state of economic system at time  $t$ . The changing in the vector time  $x(t)$  satisfies the nonlinear differential equation (synergistic equation):

$$\begin{aligned} \dot{x}(t) &= f(x(t), u(t), v(t), t), \\ t \geq t_0, x(t_0) &= x_0 \in X_0 \end{aligned} \quad (6)$$

Here  $u(t) = (u_1(t), \dots, u_p(t))$  — control vector (decision-making elements) whose coordinates characterize the mode of economic activity at time  $t$ ;  $v(t) = (v_1(t), \dots, v_p(t))$  — the vector of external disturbing factors, the elements of which characterize various accidental and indefinite influences of external environment (or the effects of negative side); it may be, in particular, the vector of interference;  $t_0$  — the initial moment of time;  $X_0 \subset R^n$ .

The solution  $x(\cdot) = (x(t), t \geq t_0)$  of equation (6) determines the trajectory of development from TES to SSEOES. In this case, it is assumed that the control vectors and the interference vector satisfy the given constraints:

$$u(t) \in U, v(t) \in V, t \geq t_0, \quad (7)$$

where  $U \subset R^p$  and  $V \subset R^q$ .

The reflection  $f: R^n \times U \times V \times R \rightarrow R^n$  is defined by the economic laws and / or balance ratios and corresponds to the real economy.

So, it is necessary to define the control vector (vector of economic decisions) that provides the “optimal” in some given sense the movement (development) from TPP to SSEOES and satisfies the set requirements that can be formalized in the form of conditions:

$$x(T) \in X_T, x(t) \in X_S \text{ at } 0 \leq t \leq T, \quad (8)$$

where  $X_T$  — the phase space of admissible (desirable) states of SSEOES;  $X_S$  — safe transition area;

$T = \phi(x(\cdot))$  — the moment of falling into the desired state (i.e. moment of first hits  $x(t)$  in a great number  $X_T$ ).

We note that here the problem is solved under conditions of uncertainty over the vector  $v(t)$  and either programmatically (which is not entirely acceptable for modern economic systems) in the form of a definition of control  $u(\cdot) = (u(t), t \geq t_0)$  at the initial moment  $t_0$  as a fixed function of time defined over the entire subsequent time interval, or by the inverse principle communication (and adaptively according to information), when the control is formed during the transition depending on the incoming information and new knowledge, for example, in the form  $u(x(t))$ .

Assuming that in the process of transition from TES to SSEOES, it is possible to measure (obtain) observations of only some part of the components of  $x(t)$  vector, for example, the first ( $m < n$ ) components (i.e. a vector  $X_m(t) = (x_1(t), \dots, x_m(t))$ ). Then the control  $u(t)$  is defined as a function of  $X_m(t)$ , from the incoming information:  $u(t) = F(x_m(t)), t \geq t_0$ , where  $u(t) \in U$  the definition of a function  $F$  is a control strategy and a  $F \in \mathfrak{S}$  set of valid strategies.

Thus, the task of transition (development) managing is to construct a strategy  $F^0$  that guarantees the fulfillment of the following conditions: for the interference vector  $v(t) \in V$  and the initial state  $x_0 \in X_0$  for the trajectory  $x(\cdot) = (x(t), t \geq t_0)$  of controlled TES transition which is described by the equation:

$$\dot{x}(t) = f(x(t), F^0(x_m(t)), v(t), t). \quad (9)$$

The conditions (7) must be observed. Let be  $\mathfrak{N}[X_0, F]$  — the set of transition trajectories  $x(\cdot)$  of system:

$$\begin{aligned} \dot{x}(t) &= f(x(t), F(x_m(t)), v(t), t), \\ x(t_0) &= x_0 \in X_0, t \geq t_0, \end{aligned} \quad (10)$$

which is obtained by sorting through all the starting points  $x_0 \in X_0$  and all permissible interference  $v(\cdot) = (v(t) \in V, t \geq t_0)$ . Denote as  $\bar{\mathfrak{N}}$  — the set of all continuous functions  $x(\cdot)$  for each of which the conditions are fulfilled:

- there is a time  $T = \phi(x(\cdot))$ , the first time  $x(t) \in X_T$ ;
- condition of risk-free transition (development) is satisfied, fulfillment of the condition  $x(t) \in X_S$  in interval  $t_0 \leq t \leq T(x(\cdot))$ .

Thus, considering the task of controlling the phase transition (development) can be reformulated as follows: in the class of admissible strategies, it is required to define a strategy  $F^0 \in \mathfrak{S}$ , for which the condition is true  $\aleph[X_0, F^0] \subset \bar{\aleph}$ .

To formulate one of variants of this problem, let us introduce some functional of effective control given on the development paths of system, i.e. the quality of strategy  $F^0$  is evaluated by the value of the functional  $J$  that it takes on the most unfavorable trajectory from the beam  $\aleph[\Omega_0, F]$ , where  $\Omega_0 = t_0 \times X_0$  is the initial development space.

Now we can formulate a particular problem of strategy optimization.

It is required to determine a strategy  $F$ , that satisfies the condition:

$$T^*[\Omega_0, F^0] = \min_{F \in \mathfrak{S}} \sup_{x(\cdot) \in \aleph[\Omega_0, F^0]} J[x(\cdot)].$$

If the optimum of functional  $J[x(\cdot)]$  is not achieved then for an arbitrarily small one  $\varepsilon > 0$ , a strategy  $F_\varepsilon$  can be defined such that:

$$T^*[\Omega_0, F^0] = \min_{F \in \mathfrak{S}} \sup_{x(\cdot) \in \aleph[\Omega_0, F^0]} J[x(\cdot)] + \varepsilon.$$

This setting can be called a game, in which the choice of  $F$  is the strategy of the 1<sup>st</sup> player, and the choice is the strategy of the 2<sup>nd</sup> player. Game and optimal methods for solving this problem have been developed by many domestic and foreign scientists [1].

6. A variant of the socio-ecological and economics model of dynamics and a technogenic industrial enterprise / region (TIE / TR) [15–19]:

$$\dot{K}(t) = -\alpha K(t) + e^\theta F(K, L, R) - C(t) - D(t),$$

$$K(0) = K_0,$$

$$F(K, L, R) = \left[ \beta_1 K^{\frac{\delta-1}{\delta}} + \beta_2 L^{\frac{\delta-1}{\delta}} + \beta_3 R^{\frac{\delta-1}{\delta}} \right]^{\frac{\delta}{\delta-1}}.$$

$$\dot{L}(t) = \gamma L(t) - \gamma_Z Z(t) + \gamma_C C(t), L(0) = L_0,$$

$$\dot{R}(t) = \gamma_R R(t) + \gamma_K K(t) - Q(t) - \gamma_L L(t),$$

$$R(0) = R_0$$

or

$$\dot{R}(t) = d(K(t), L(t)) + \gamma_K K(t) -$$

$$- \gamma_L L(t) - Q(t), R(0) = R_0.$$

$$\dot{Z} = f^*(c, K, L, R)(1 - \eta c) - g(Z), Z(0) = Z_0.$$

$$F(K, L, R) = \left[ \beta_1 K^{\frac{\delta-1}{\delta}} + \beta_2 L^{\frac{\delta-1}{\delta}} + \beta_3 R^{\frac{\delta-1}{\delta}} \right]^{\frac{\delta}{\delta-1}},$$

where  $Y$  – the volume of “useful” output,  $K$  – a capital,  $L$  – the number of workers (labor),  $C$  – the volume of consumption,  $Z$  – the amount of pollution (“harmful” output),  $I$  – the investments,  $R$  – other resources,  $D$  – expenditure to monitor and reduce pollution.

Then the three points in this model determines the environmental and economic strategy for the development of TIE / TR, and a  $u = (C, Y, Z)$  is the vector (strategy) of environmental and economic management.

7. Modeling of ecological economics optimal management of the TIE / TR [1].

7.1. A variant of ecological and economic model of the TIE. Since the increment (growth) of pollution is equal to the difference between the volume of pollution produced and the volume of pollution eliminated due to direct control, as well as a result of natural decrease (assimilation), the dynamics of pollution in general can be described by the following differential equation:  $\dot{Z} = Z^+ - Z^-$ , where for the TIE  $Z^+ = \gamma f(k)$ ,  $Z^- = \lambda(1 - \alpha - \beta)f(k) + \delta z$ , and for the regional economy as a whole, in particular for the technogenic region (in the case of mutual independence of the TIE):

$$Z^+ = \sum_1^n \gamma_i f_i(k_i),$$

$$Z^- = \lambda \sum_1^n (1 - \alpha_i - \beta_i) f_i(k_i) + \delta z.$$

Suppose that a rate of accumulation  $\rho = \alpha = \alpha(t)$  is a variable. Then the specific consumption can be calculated as:

$$c(t) = (1 - \alpha(t))(1 - a)f(k) =$$

$$= (1 - a)f(k) - \alpha(t)(1 - a)f(k)$$

or

$$\alpha(1-a)f(k) = (1-a)f(k) - c(t).$$

In this case, the equation of funds dynamics will take the form:

$$\begin{aligned} \dot{k} &= -(\mu + \nu)k + \alpha(1-a)f(k) = \\ &= -(\mu + \nu)k + f(k) - c, \end{aligned}$$

or

$$\dot{k} = f(k) - (\mu + \nu)k - c(t), \quad k(0) = k_0. \quad (11)$$

7.2. If, for example, an issue is defined as  $Y = F(K, L)$ ,  $Y = I + C$ , a modified model of funds dynamics, taking into account the delay of investment flows (with a distributed lag and when the kernel functions  $h(t - \tau) = h_0 \exp(-r(t - \tau))$ , i.e. for the stationary case) takes the following form [1, 4] (12):

$$\begin{cases} \dot{K} = -\mu K + I_h(t), \quad K(0) = K_0, \\ \dot{L} = \nu L \quad \text{or} \quad L = L_0 e^{\nu t}, \quad L(0) = L_0, \\ \dot{I}_h = -r I_h + h_0 I, \quad I_h(t_0) = h_0 I(t_0), \end{cases}$$

or

$$\begin{cases} \dot{k} = -(\mu + \nu)k + i_h(t), \quad k(0) = k_0, \\ (\dot{i}_h)' = -(r + \mu + \nu)i_h + h_0 \rho f(k), \quad i_h(0) = i_{h0}, \\ c = (1 - \rho)f(k), \quad (\rho \equiv \alpha). \end{cases} \quad (12)$$

At the same time, it should be noted that the investment flow is also a stochastic process.

Equation (12) is the main dynamic model of a controlled production system (PS) and as a control variable, we can take the specific consumption  $c(t) = C(t)/L(t)$  or rate of accumulation  $\rho$ , and the state variable  $k(t)$  – is the capital-labor ratio, i.e.  $k(t) = K(t)/L(t)$ .

7.3. Nonlinear modified dynamic model of the production system with the logistic nature of the change  $L$ . Traditionally, an exponential change in labor resources is assumed, i.e.  $L(t) = L_0 \exp(n_0 t)$ ,  $L_0 \equiv L(t_0)$ , where  $n_0$  – the parameter of growth rate, i.e.  $\dot{L} = n_0 L$ . However, taking into account the effect of “saturation” there is a more realistic model of the dynamics of labor resources in the form of logistic equation:

$$\dot{L}(t) = n_0 L(t) \left( 1 - \frac{L(t)}{L_{\max}} \right),$$

where  $L_{\max}$  – the maximum allowable amount of labor resources (the maximum allowable number of employees in this system).

Therefore, we will have the following model of functioning and development of the TIE:

$$\begin{cases} Y(t) = F[K(t), L(t)], \\ C(t) = (1 - \alpha)Y(t), \\ \dot{K}(t) = -\mu K(t) + \rho Y(t), \\ K(t_0) = K_0 - \text{initial fixed assets}, \\ \dot{L}(t) = n_0 L(1 - L/L_{\max}), \\ L(t_0) = L_0 - \text{initial amount TP}. \end{cases} \quad (13)$$

For the convenience of syem analyzing, we turn to relative (specific) values:  $k = K/L$  – capital-labor ratio;  $c = C/L$  – consumption per worker;  $y = Y/L$  – labor productivity.

Then the system of equations (13) can be rewritten in the following form:

$$\begin{cases} y(t) = f(k) \equiv F(k, 1), \\ c(t) = (1 - \alpha)y(t) = (1 - \alpha)f(k), \\ \dot{k}(t) = \alpha f(k) - n_0 \cdot k \cdot (1 - \eta), \\ \eta = L/L_{\max}, \quad 0 < \eta < 1, \\ k(t_0) = k_0. \end{cases}$$

Thus, we have a nonlinear dynamic model:

$$\begin{cases} \dot{k}(t) = \alpha f(k) - n_0 (1 - \eta(t))k(t), \quad k(t_0) = k_0, \\ c(t) = (1 - \alpha)f(k), \\ \dot{\eta}(t) = n_0 \eta(t)(1 - \eta(t)), \quad \eta(t) \equiv L(t)/L_{\max}, \\ \eta(t_0) = L_0/L_{\max}. \end{cases} \quad (14)$$

Since the dynamics model of labor resources has the form:

$$\dot{L} = n_0 L \left( 1 - \frac{L}{L_{\max}} \right)$$

or

$$\dot{L}/L = n_0 \left( 1 - \frac{L}{L_{\max}} \right) \equiv n_0 (1 - \eta(t)),$$

that

$$\begin{cases} \dot{k} = i(t) - [\mu + n_0(1 - \eta(t))]k \\ \dot{\eta} = n_0 \eta(1 - \eta), \\ y = c + i; \quad i = f(k) - c \end{cases}$$

or



$$\begin{cases} \dot{k} = f(k) - c - [\mu + n_0(1 - \eta(t))]k, & k(t_0) = k_0, \\ \dot{\eta} = n_0\eta(1 - \eta), & \eta(t_0) = L_0 / L_{\max}, \quad 0 < \eta(t) < 1. \end{cases}$$

So, for the TIE, as an integral ecological and economic model of dynamics, we can consider equations (11) or (12) with a state vector  $x = (k, z)$  and a control vector of variables  $u = (\alpha, \beta)$ .

The task of optimal control of the TIE can be presented in the following statement.

Let we take as a utility function  $U(q) \equiv U(k, z, \alpha, \beta) \equiv U(x, u)$ , and the efficiency (optimality) functional –

$$J(q) = \int_{t_0}^T \exp(-\delta t) U(q(t)) dt.$$

Then the problem of the optimal EED will take the form:

$$J(q) \rightarrow \max_{q \in Q} (opt),$$

Under the restrictions:  $0 \leq \alpha, \beta \leq 1, \alpha + \beta \leq 1$ , also

$$Q = \{(\alpha, \beta, k, z) \mid 0 \leq \alpha, \beta \leq 1; \alpha + \beta \leq 1, k(t_0) = k_0, z(t_0) = z_0\}$$

or

$$Q = \{(\alpha, \beta, k, z) \mid k(t_0) \in K_0, k(T) \in K_T, z(t_0) \in Z_0, z(T) \in Z_T\}.$$

8. The cyclic dynamics models and a generalized logistic equation to describe the sustainable development processes and technologies. The process of each technology development in the most general, approximate form is described by a logistic curve determined by a differential equation of form [25]:

$$\frac{dy}{dt} = \alpha(y - k_1)(k_2 - y) \tag{15}$$

Where  $t$  – is a parameter that expressing the total costs of society for the development of this technology (it can be time, energy or abstract social labor, expressed in cost form),  $y(t)$  – is the technologically significant result achieved by this technology,  $\alpha$  – is a positive constant (“scale” parameter),  $k_1$  and  $k_2$  – are positive constants that limit (technically lower and upper) the technolo-

gically significant result of this technology functioning. Moreover,  $k_1$  – is the lower boundary  $y(t)$ , which expresses the initial, starting, and extremely low capabilities of the technology, and  $k_2$  – is its technological limit characterizing its maximum capabilities.

With an increase in the costs of mastering and improving this technology, its technologically significant result can only increase; therefore,  $y(t)$  is a function that grows monotonously throughout the entire area of its definition. The fact that the first derivative (growth rate) of  $y$ , according to equation (15), is directly proportional to the separation of this quantity from its starting capabilities, means that  $y(t)$  grows faster, the larger this separation. On the other hand, the proportionality of the first derivative to the value  $(k_2 - y)$  means a slowdown in the growth of  $y(t)$  as it approaches to its technological limit.

The logistic (S-shaped) curve describing the life cycle of each individual technology (Fig. 4) can be considered as a model of the dynamics of various cumulative quantities, so that the rate of further growth of such quantities is proportional to their existing value.

Logistic curves describe the cumulative growth with saturation; meaning that accumulating value has an upper limit, as it approaches its growth slows down.

With such cumulatively growing quantities that not only the dynamics of individual technologies are described, but also the scientific and technological development of society as a whole. For example, N.D. Kondratiev noted [24] that the level of technology as a quantity allows quantitative measurement and exerts a quantitatively measurable effect on the elements of economic life is a cumulative quantity whose dynamics obeys a law expressed by a differential equation of the form (15).

From time to time in society, the process of replacing technologies is performed, i.e. the change in the prevailing technology, in accordance with which the bulk of the entire mass of given use value, a given product of human labor, is produced. The displacement of technology from production processes and its replacement with a more progressive one is called a technological leap. The process of replacing technologies, the dynamics of each is expressed by a logistic curve.

For the practical calculations the period of technological gap can be considered, as shown in the figure, the time between the closest points of local

maximum curvature of two adjacent logistic curves (that is, between the points closest to each other, where these adjacent curves are most “convex”).

Fig. 4 have more general meaning than the illustrations to the development process of individual technologies or to the life cycles of innovations

Overall, the development of productive forces of society (both locally and globally) appears as a cumulative process, the dynamics of which obey the logistic law.

In the modern world economy the duration of industrial cycles is reduced, and the most significant are becoming the long waves of economic conditions, which are the information cycles (Konratiev’s cycles), the dynamics of which are based on the universal laws of aggregate social knowledge development and are associated with the life cycles of corresponding technological structures.

These information cycles the duration of each is 50-60 years, also do not cancel either agrarian or industrial cycles, exist along with them, but gradually acquire a decisive, dominant influence on the nature of economic dynamics, on the course of macroeconomic processes.

The current stage of economic development gives reason to say that medium-term cyclical factors are increasingly fading into the background compared with the factors of a structural long-term nature, that the classical cycle is being formed within the framework of a large cycle of economic conditions. This fact, generally speaking, means that in modern conditions, the long-term economic interests have priority, dominant nature compared with short-term, current ones, and the assessment of the long-term consequences of decisions taken is of primary importance.

The life cycle of each technological structure lasts on average about 100 years.

The first of them falls at the beginning of the technological mode development due to technological, internal reasons caused by the laws of new technologies proposals, when this structure makes its way into an alien socio-economic environment.

The second rise is at the beginning of the second half of its life cycle, when economic relations in society have already transformed sufficiently to absorb the technological innovations offered by this structure. This rise was caused not by the technological, but economic reasons, external to the development of the technological basis of production, and expresses the readiness of society for the implementation of relevant innovations and a

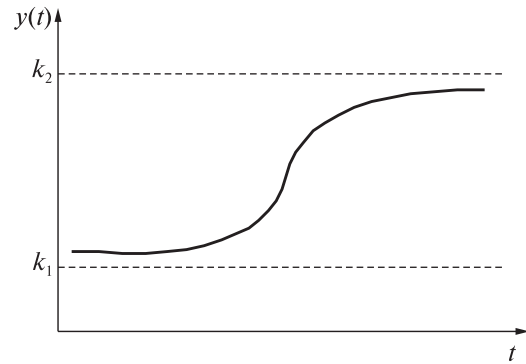


Fig. 4. Logistic curve

regular increase in public demand for them. Note that these two impulses in the development of technological structures – endogenous and exogenous – generally express the quantitative dynamics of various progressive-cyclic processes; therefore, this model can serve to describe many similar phenomena in nature and society. In relation to the quantitative dynamics of technological structures, this model is called as the hypothesis of Grubler–Fetisov and allows to predict with sufficient accuracy the onset of transitional and crisis periods in the development of technical and economic macro-systems and individual technologies.

In general, the replacement of technological structures is carried out according to the law, which is mathematically described by a generalized logistic curve. This function satisfies the differential equation for fixed constants  $k_1$  and  $k_2$  ( $k_2 > k_1 > 0$ ), which express the technological limits characteristic of a given technological structure, so that for all  $t$ :  $k_1 < y(t) < k_2$ :

$$\frac{dy}{dt} = \alpha(t)(y - k_1)(k_2 - y).$$

The solution of this equation is the function

$$y(t) = k_1 + \frac{(k_2 - k_1)\Lambda(t)}{\Lambda(t) + \beta} \quad (16)$$

for arbitrary  $b > 0$ , where

$$\Lambda(t) = \exp \left[ (k_2 - k_1) \int_{t_0}^t \alpha(\tau) d\tau \right].$$

In the model under consideration, time does not flow linearly, but in a sense is proportional to the function  $\alpha(t)$ . Therefore, the form of the function  $y(t)$  essentially depends on the function  $\alpha(t)$ .

The simplest case  $\alpha(t) = \text{const}$  leads to the Fischer – Pry technological shift model, which was first considered by N.D. Kondratiev in 1934. Less the function  $\alpha(t)$  resembles a constant, the events more non-linearly described by this model are developing.

In some cases, pulse type function should be considered as  $\alpha(t)$  its peak at a certain moment in time  $t_1 > t_0$ . For example, a function of the form  $\alpha(t) = \alpha / [(t - t^*) + \gamma]$  where  $\alpha, \gamma > 0$ , agrees well with the hypothesis of a “double” wave of technological structures replacement. In this model, the first time rise is due to the logistic nature of the functions growth of type (16), that is, it has an endogenous nature, and the second is caused by local “compression” of time at time  $t_1$ , that is, it is determined by exogenous reasons.

A generalized logistic curve with an arbitrary number of inflection points can be considered as a model of the learning processes of complex dynamic systems [25], in which periods of evolutionary, gradual and revolutionary, spasmodic development alternate. In this case, wave-like oscillations are superimposed on the translational trend, so that in general the development of such systems appears as a translational-cyclic process.

9. The issue of sustainable development and the “heptagon” of the main assets (capitals) supported by the vital activity of the SEES [26, 27] (Fig. 5).

The generalized production and technological function (PTF) can be represented as:  $Y(t) = F[K, L, H, N, \Phi, S, I; \bar{c}]$ . It can be used to study sustainable development.

The concept of sustainable development. Theory and practice testify that at the turn of the century the teachings of V.I. Vernadsky on the noosphere proved to be a necessary platform for developing a triune concept for sustainable environmental, social and economic development. A generalization of this concept was done at the

UN world summits in 1992 and 2002, in which more than 180 countries of the World, many international organizations and leading scientists took part. Thus, the new concept systematically united the three main components of sustainable development of society: economic, environmental and social.

The economic approach consists in the optimal use of limited resources and the use of environmental, energy, and material-saving technologies to create a total income stream that would ensure at least the preservation (not reduction) of the total capital (physical, natural or human), using which this comprehensive income is created. At the same time, the transition to an information society leads to a change in the structure of total capital in favor of human capital, consolidating the intangible flows of finance, information, and intellectual property. Already, these flows exceed the volume of tangible goods movement by 7 times [ru.wikipedia.org].

The development of a new, “weightless” economy (knowledge economy) is stimulated not only by a shortage of natural resources, but also by an increase in the volume of information and knowledge acquiring the significance of the requested product.

From an environmental point of view, sustainable development should ensure the integrity of biological and physical natural systems, their viability, and the global stability of the entire biosphere depends on this. Of particular importance is the ability of such systems to self-renew and adapt to various changes, instead of being preserved in a certain static state or degradation and loss of biological diversity.

The social component is oriented towards human development, maintaining the stability of social and cultural systems, and reducing the number of conflicts in society. A person should not become an object, but a subject of development.

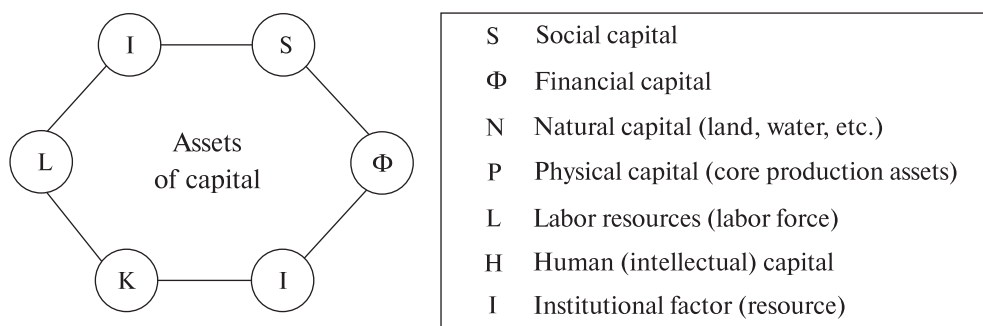


Fig. 5. Assets of capital

Person must take part in the processes of the formation of life, adoption and implementation of decisions, control over their implementation. Equitable distribution of benefits between people (reduction of the so-called GINI index), pluralism of opinions and tolerance in relations between them, preservation of cultural capital and its diversity, especially the heritage of non-dominant cultures, are important for ensuring these conditions.

Systematic coordination and balancing of these three components is a task of enormous complexity. In particular, the interconnection of social and environmental components leads to the need to preserve the same rights of present and future generations to use the natural resources. The interaction of social and economic components requires the achievement of justice in the distribution of wealth between people and the provision of targeted assistance to the poor. Finally, the interconnection of environmental and economic components requires a valuation of technogenic environmental impacts. The solution of these problems is the main challenge of today for national governments, authoritative international organizations and all progressive people in the world.

The system of global dimensions of sustainable development. An important problem on the way of implementing the concept of sustainable development is the formation of a measurement system (indices and indicators) for quantitative and qualitative assessment of this very complex process. The main requirements for this measurement system are its informational "completeness" and the adequacy of the presentation of an interconnected triad of sustainable development components. Both well-known international organizations and numerous research teams are working in this direction, but so far, they have not been able to reach an unambiguous agreement on this measurement system.

Institute for Applied System Analysis Ministry of Education and Science of Ukraine and the National Academy of Sciences of Ukraine has proposed a specific system for measurement of sustainable development [26, 27].

We will evaluate the level of sustainable development (LSD) with the help of corresponding index, which is calculated as the sum of the indices for four dimensions (areas): Economic ( $I_{\text{эко}}$ ), Environmental ( $I_{\text{экл}}$ ), Social ( $I_{\text{соц}}$ ) and Humanitarian ( $I_{\text{гум}}$ ) with corresponding weighting factors, t.e.

$$I_{\text{yp}} = \alpha_1 I_{\text{эcn}} + \alpha_2 I_{\text{экл}} + \alpha_3 I_{\text{соц}} + \alpha_4 I_{\text{гум}}$$

In turn, each of the indices  $I_{\text{эcn}}$ ,  $I_{\text{экл}}$ ,  $I_{\text{соц}}$ ,  $I_{\text{гум}}$  will be calculated using well-known international indices and indicators.

The conditions for sustainable development (SD) are defined as follows.

1. The condition of weak stability:  $\frac{dF[\cdot]}{dt} \geq 0$ ,  
or

$$F_{t+1}[\cdot] \geq F_t[\cdot],$$

where

$$F_t[\cdot] \equiv F[K(t), L(t), H(t),$$

$$N(t), \Phi(t), S(t), I(t), \bar{c}].$$

2. The condition of strong stability:

$$\frac{dF[\cdot]}{dt} \geq 0, N = N^C + N^S$$

or

$$\frac{dN^C}{dt} \geq 0,$$

or

$$N_{t+1}^C \geq N_t^C,$$

where  $N^C$  — is a critical part of natural capital, and  $N^S$  — is natural capital, which can be replaced with artificial.

For example, taking into account the critical natural capital  $N^C$ , sustainable development can be supplemented by a restriction on the exhaustion of this quantity in time. For a production function that does not decrease in time, the arguments of which are aggregated variables: labor —  $L$ , capital —  $K$  and natural resource —  $N$ , will have the ratio:  $F_t(K, L, N) \leq F_{t+1}(K, L, N)$

or generally

$$F(K(t), L(t), H(t), N(t), \Phi(t), S(t), I(t), \bar{c}) \leq \\ \leq F(K(t+1), L(t+1), H(t+1), N(t+1), \\ \Phi(t+1), S(t+1), I(t+1), \bar{c})$$

and it is also necessary to observe the condition of nondecreasing in time the value of  $N^C$ , that is  $N_t^C \leq N_{t+1}^C$ , as well as the condition for the partial replacement of natural capital  $N$  with artificial (or non-renewable resource with a restored resource):  $N_t = N_t^C + N_t^S$ .

The integral level of sustainable development for all capitals (resources) can be determined, for example, in the case of a linear relationship as

$$Y_p(t) = c_1 K(t) + c_2 L(t) + c_3 H(t) + c_4 N(t) + c_5 \Phi(t) + c_6 S(t) + c_7 I(t)$$

or, in the case of a multiplicative dependence, the production and technological function will have

$$Y_p(t) = c_1 K^{d_1}(t) L^{d_2}(t) H^{d_3}(t) \times N^{d_4}(t) \Phi^{d_5}(t) S^{d_6}(t) I^{d_7}(t),$$

where  $c_1, c_2, c_3, c_4, c_5, c_6, c_7$  — weight (normalizing and scaling) coefficients,  $d_1, d_2, d_3, d_4, d_5, d_6, d_7$  — relevant indicators of resource elasticity.

In the general case, the integral level of sustainable development can be represented as a nonlinear function:

$$Y_p(t) = F[K(t), L(t), H(t), N(t), \Phi(t), S(t), I(t); \bar{c}].$$

Private versions of the PTF model:

a) Mankiw – Romer – Weil model. The option of accounting for human capital ( $H_c$ )  $\equiv$  ( $H$ ) in the production function (PF), along with physical capital ( $K$ ), labor ( $L$ ) and natural resources ( $N$ ):

$$Y(t) = K^\alpha(t) \cdot H^\beta(t) \cdot [A(t) \cdot L(t)]^{1-\alpha-\beta},$$

where  $\alpha, \beta > 0$ ;  $\alpha + \beta < 1$ ;  $H(t) \equiv H_c$ ;  $A(t)$  — is the function of scientific and technological progress. Note that a  $\alpha$  — is the share of capital, which is

provided by the growth of investments (cost capital); similarly  $\beta$ .

b) A model for accounting for all fixed assets:

$$Y(t) = A(t) K^\alpha(t) L^\beta(t) H^\gamma(t) \times S^p(t) \Phi^q(t) N^\tau(t) I^\upsilon(t),$$

where  $\alpha, \beta, \gamma, p, q, \tau, \upsilon > 0$  and  $\alpha + \beta + \gamma + p + q + \tau + \upsilon = 1$ .

Here the following notation is also used:  $K$  — physical capital,  $L$  — labor force (labor),  $H$  — human capital,  $S$  — social capital,  $\Phi$  — financial capital,  $N$  — natural resources (land, water, etc.),  $A(t)$  is a function of the level of scientific, technical and technological development, for example,  $A(t) \equiv aT^S(t)$ , where  $T(t)$  is the volume of innovative technologies (resources) [28].

**Conclusion.** The family of models that presented in the work can be discussed and used in order to create the integrated information systems for environmental-economic and socio-humanitarian management of various socio-organizational systems of different levels and especially economic objects of anthropogenic nature to ensure a stable and sustainable development. The proposed models of nonlinear SEE dynamics have both independent theoretical significance and are applicable in the problems of assessment, forecasting, management, and decision making under conditions of instabilities and complex informational conditions.

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#### ИНТЕГРАЦИОННАЯ МОДЕЛЬ УСТОЙЧИВОГО РАЗВИТИЯ

Представлена интеграционная модель устойчивого развития как семейство моделей по созданию интегральных информационных систем эколого-экономического и социогуманитарного управления различными социально-организационными системами и особенно экономическими объектами техногенного характера для обеспечения устойчивого и жизнеспособного развития. Рассмотрена проблема устойчивого развития через

«семиугольник» основных активов (капиталов), поддерживающих жизнедеятельность социо-эколого-экономических систем. Описана концепция, система глобальных измерений и уровень устойчивого развития.

**Ключевые слова:** интеграционная модель, устойчивое развитие, экономико-математическая модель, социо-эколого-экономическая система.

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## ІНТЕГРАЦІЙНА МОДЕЛЬ СТАЛОГО РОЗВИТКУ

Представлено інтеграційну модель сталого розвитку як сімейство моделей щодо створення інтегральних інформаційних систем екологоекономічного та соціо-гуманітарного управління різними соціально-організаційними системами і особливо економічними об'єктами техногенного характеру для забезпечення сталого і життєздатного розвитку.

Розглянуто концептуальну модель інтегрального еколого-економічного, соціо-гуманітарного розвитку та управління складною системою в умовах невизначеності, нестабільності, складності; концептуальну модель прогнозування та управління еколого-економічними процесами техногенного об'єкта; інтегральну соціо-еколого-економічну динамічну модель поведінки з духовно-моральними змінними; синергетичну модель нелінійної динаміки інтегральної стохастичної системи з хаотичною поведінкою; моделювання еколого-економічної динаміки управління розвитком техногенної системи в умовах невизначеностей і ризиків; варіанти соціо-еколого-економічної моделі динаміки техногенного промислового підприємства / регіону; моделювання еколого-економічного оптимального управління територіями пріоритетного розвитку; моделі циклічної динаміки і узагальнене логістичне рівняння для опису процесів сталого розвитку і технологій.

Розглянуто економічний підхід до моделювання сталого розвитку, який полягає в оптимальному використанні обмежених ресурсів і застосуванні природо-, енерго- та ресурсощадних технологій для створення сукупного доходу, який забезпечував би принаймні збереження (не зменшення) сукупного капіталу (фізичного природного або людського), з використанням якого цей сукупний дохід формується. Перехід до інформаційного суспільства призводить до зміни структури сукупного капіталу на користь людського, збільшуючи нематеріальні потоки, потоки інформації та інтелектуальної власності.

Надано діаграму «чотириєдної» інтегрованої системи розвитку, схему об'єктно і суб'єктно орієнтованого управління і ухвалення рішення, логістичну криву, схему динаміки інновацій і технологічних укладів й активів капіталу.

Розглянуто проблему сталого розвитку через «семикутник» основних активів (капіталів), що підтримують життєдіяльність соціо-еколого-економічних систем. Визначено концепцію, систему глобальних вимірів і рівень сталого розвитку.

**Ключові слова:** інтеграційна модель, сталий розвиток, економіко-математична модель, соціо-еколого-економічна система.