USING GRAPH-ANALYTICAL METHODS MODELING OF SYSTEM OBJECTS TO DETERMINE INTEGRATED ASSESSMENT OF THEIR STATE

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In article is determined of object state in researching "system – environment" based on system analytic-graph modeling for representation real relationships and relations between any systems in nature. Justified non-standard solution according to forecasting states and changes results in "system – environment" based on constructed cognitive models and entropy analysis for action direction sustainability and implemented situations assessment. Practical usage of systematic methodological support for complex objects comprehensive research based on graph models sequential analysis. To analyze physical processes displacements between simple ideal system components, which are sources of potential and kinetic energy, changes in its capacity through matter or energy accumulation, is used structural graph – physical processes topological model.

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1. INTRODUCTION

Modern system theory presupposes the existence of systemic entities in the form of socio-economic, socio-ecological, ecological and economic objects of natural and man-made content, which relate to complex systems, and, in accordance with sustainable development provisions, they are united in socio-ecological and economic research objects [1, 2]. A special component for such systems is an information component that takes into account the qualitative characteristics of both individual elements and their relationships. The unstable systems state leads to crises that are conventionally equated with qualitative transformations in them. Thus, the study of modern complex systems is becoming relevant in the processing of information data in accordance with the standard system approach and the latest methods of information theory [3].

Decision-making is an analogue of information exchange and is the basis of activity, including management. The decision is determined by the achievement of the goal in choosing the best (more acceptable, optimal) alternative from possible variety of options for the purpose.

Under the research object study or development in accordance with the general definition of J. Clare [1] is understood part of the world, which for a given period of time is a unit that reflects the natural (ecological), economic and social aspects of life. The object interacts with environment, which is central to the investigated integrity [3] (as opposed to existing approaches in solving complex system problems, because it is the basis of the functionality of the object).

2. THE STUDY GOAL AND TASKS

Investigated object assessment, organizational structure and multifunctionality by components expense, multidimensionality and knowledge diversity in proper systems determining, initial conditions for their creation, require a system analysis, enhanced to manage situation or support / change the system by a new element / property. A special feature of such an analytical center should be complexity, information efficiency of state and processes identification in components and object in general, taking into account environment and interaction with it, which creates uncertainty at inaccuracies, fuzziness, incompleteness information providing complexity increase and corresponding knowledge lack of it nature for different systems – technical, economic, social, biological, ecological. Thus, the task of creating not just an information system as in the analysis object, but also the information shell toolkit, which allows to give an assessment and integrate into a single information space knowledge about system and process solved in such tasks:

1) determination of object state in researching "system – environment" based on system analytic-graph modeling for representation real relationships and relations between any systems in nature;

2) justification of non-standard solution according to forecasting states and changes results in "system – environment" based on constructed cognitive models

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and entropy analysis for action direction sustainability and implemented situations assessment;

3) practical use of systematic methodological support for complex objects comprehensive resaech based on graph models sequential analysis.

3. SCIENTIFIC RESULTS

Information visualization about the system as a research object is widely used in various activity fields: biological sciences, artificial intelligence, financial information analysis, etc. At solving complex problems of studying state and functional correspondences at interaction "system – environment" at resaerch level "state – process – state" proposed to refer to topological models – observational graphical display of elements efficiency and system in whole to determine system state indicators, taking into account its structure, elements interaction, functionality and external influence both from the side of environment and control action.

Topological models contain structural (structural-logical) schemes, parametric graphs, logic-functional graphs (transitions intensity and state changes), signal graphs, tree failures.

Organizing optimizing communications task solving in complex systems from the determining standpoint it state and possible adjustments assessment in order to achieve maximum systems functionality and interaction with environment, have to deal with information flows and a significant amount by calculation and logical procedures. In this case, it is appropriate to use analyzed objects topological models in form of information flow multigraphs, parametric information and signal graphs, using optimal strategy algorithms.

Topological model appling allow using the information on GIS and establish investigated system state and its relations with surrounding systems of different nature: natural, namely ecosystems, social and economic, formed natural-technogenic research object for "state – process – state" analysis. This approach involves the consistent solution of deterministic tasks, statistical nature of information support and dynamic, associated with influence on system, processes in it and the regulatory action on it to achieve stationary sustainable development. Combination of topological and cognitive models is suggested, where information base is taken for factors study as self-regulating mechanisms definition for "system – environment", decisions on this system object quality management.

To analyze physical processes displacements between simple ideal system components, which are sources of potential and kinetic energy, changes in its capacity through matter or energy accumulation, is used structural graph – physical processes topological model.

It is proposed to use simpler and mathematically rigorous concept for programming with graphs loaded only on horizontal arcs by symbols, expressions, and functions from elementary mathematics. Such graph is polyglot, has the ISO 8631/1989 standard and only one is effectively used throughout software development and operation process life cycle.

Error-free design processes of algorithms, programs, data, network graphs, proof of their correctness, self-documentation and decision making documenting motivation are greatly simplified, improved and accelerated [4, 5].

Uncertainties overcoming due to unpredictable situations in systems, stochastic – in the natural and some knowledge lack about natural-technogenic formations occur according to logical analysis procedure in topological graphs system, which ensures decision-making reliability and backed by knowledge oriented base. This base consists of a corresponding information set on state, processes and optimization research systems and optimization decomposition principles, construction special mathematical modeling programs of complex systems. The availability of such source data and provided research objects models is the base for solving majority technical problems providing strategy building for solving research problems based on what becomes possible due to topological models in form of information stream multimographs and information graphs.

The general task model for achieving the goal in this case has form:

$$\varphi\left(m_y\right) = \sum_{i=1}^{s} \int c_i f\left(y, m_y, \sigma_y\right) dy,$$

where $\varphi\left(m_y\right)$ – estimated function – efficiency function of nominal optimum from mathematical expectation of random variable Y (indicator, factor); $f\left(y, m_y, \sigma_y\right)$ – distribution density Y: m_y, σ_y – mathematical expectation and mean square deviation respectively; c_i – utility i-th interval $\lceil y_{iH}, y_{iB} \rceil$ of values Y; $\int\limits_{Y_{iH}}^{Y_{iB}} f(y, m_y, \sigma_y)$ – probability of falling y in i-th values interval.

For ecological and economic tasks of environmental quality management denomination is a value that corresponds to objective homeostasis function while preserving natural environment quality Y: $m_y = m_{ynom}$. Thus, the denomination search – setting for these conditions such relationships and processes of systems coexistence within an object that provides the minimum energy tension and corresponding maximum entropy that does not lead to its changes m_y^0, that is, maximum systems ordering, effective functionality maximum: $\max\limits_{my} \varphi(m_y) = \varphi^0$. Target changes achievement in the best way by maximizing rule of generalized efficiency function of nominal optimum takes the form:

$$\varphi^0 \max_{my} \varphi\big(M_h, t\big) = \iint\limits_S ... \int C(y) f\big(y, M_h, t\big) dcdydt,$$

taking into account the constraints on the generalized efficiency function as moments control condition M_h

distribution: $f(y, M_h)$: $M_h = \varphi(X, t), h = 1, 2, 3, 4$ and constraints on managing factors $X \in X_{add}$ and resultant one $Y \in Y_{add}$.

In complex systems analysis, identification it state in quality management terms, it is advisable to switch to cognitive models, which allows to determine possible variants of its behavior by pulsed modeling on cognitive maps, obtain the necessary implementations number of pulsed processes [6, 7].

Cognitive modeling technology allows to determine possible and rational situation managing ways in order to transition from initial to goal states according to revealed factors of significant impact on events development in system with internal changes in it and external interaction with environment [8]. Thus, cognitive model determines system state and its occurrence in certain situation in general – "system – (system – environment) – process – situational system state", based on logic, knowledge and experience.

In practice dynamic systems dominate, where different processes take place both in nature, society and in technical devices, and it is therefore advisable to refer to such system definition provided by Optin [9]: system is a process that goes. It is therefore necessary to substantiate the basis for the synthesis and analysis of various specific complex systems. Such system must include the object as material physical education, processes that occur when it interacts with environment, in it with self-regulation, support and homeostatic relations restoration with the environment, stochastic transformations with new system structure self-organization. Structural research continuity, for such complex systems, is ensured by research system model image usage in form of topological graph.

Topological models – graph, simplicial complex, CW-complexes, provide system analysis integrity under conditions of polydisciplinary approach usage when considering problem tasks in assessment and objects study based on psychology knowledge and system representations about social systems, animate and inanimate nature, man-made environments organization that provide symbiotic relations between man and technical systems.

Taking into account introduced symbols according to researched object components: X_1, X_2, X_3, X_4 – economic, social and ecological systems state and environment according to influence independent variable as assessment start X_0 – input value represented as a three-contour oriented graph, which is generalized model of dynamic system and processes in it (Fig.1).

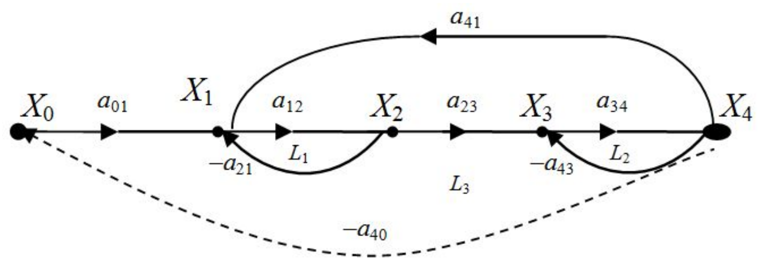

Fig.1. *System object structure schema in form of topologic model – oriented graph* $G = G(X, A)$*:* $X_{i,j}$ *– coordinate set of analized system, where i – system number, where information received; j – system number, wich have influence, give an information; A – set of all connections between systems* a_{ji}

Intoduced graph represents a system object, which is defined by three closed loops structure, two of which have inverse negative bonds and one common with positive inverse bond, external inverse information bond – a_{40}. Each system in such interaction with environment characterized by certain informativeness level, which depends on information communications state a_{ji}, i.e. $x_i = \sum\limits_{i=0}^{N} a_{ji} x_i, i = \overline{0, N}$, where N – systems number involved in analysis with environment consideration – "system – environment". According to structure object, presented as topological graph in Fig.1, following informativeness is determined for systems:

$$\left.\begin{aligned} x_1 = a_{01}x_0 - a_{21}x_2 + a_{41}x_4; \\ x_2 = a_{12}x_1; \\ x_3 = a_{23}x_2 - a_{43}x_4; \\ x_4 = a_{34}x_3. \end{aligned}\right\} \quad (1)$$

Under the provided equations system from structured scheme, graph variables are determined by Cramer method: $x_i = \frac{\Delta_i}{\Delta}$, where Δ – main system determinant; Δ_i – separate determinant. For k independent variables used expression $x_i = \frac{\sum_k \Delta_{ik} x_k}{\Delta}$.

For taking into account all information about state "system – environment" – the system properties through interactions variables and parameters, involve matrix methods: $A \cdot \check{X} = B \cdot \check{Y}$, where A, B – matrices of numerical system coefficients; X, Y – coordinates vector; or $X = CY, C = A^{-1}B$.

According to requirements of the World Bank and the International Finance Corporation, the environmental assessment of man-made systemic entities coexistence and natural is determined by information on environmental impact assessment (EIA) results, ecological audit, ecological risk assessment, environmental protection plan. When establishing this general dynamic equilibrium indicator in the corporate natural-technogenic research object representation by state and processes analysis in it along with cognitive maps structural matrices are used with corresponding purposes.

System structural components transfer functions view of direct relation W_{dr} and feedback W_{fdb} between elements determine input influence transformation x_{input} in initial characteristic of this process and dynamic changes given by operator polynomials relation:

$$\frac{x_{\text{output}}(s)}{x_{\text{input}}(s)} = W_s = \frac{Q(s)}{R(s)}, \tag{2}$$

where $Q(s)$ – personal operator of dynamic element (component, system) that characterizes its properties; $R(s)$ – communication operator between dynamic elements; s – complex variable in the Laplace transform operator, which under zero initial conditions is analogous to differentiation operator $p = \frac{d}{dt}$.

Thus, information transmission through any structural element of considered system (object) is characterized by a transfer function

$$\Phi_s = \frac{W_{\text{dr}}(s)}{1 - W_{\text{dr}}(s) \cdot W_{\text{fdb}}(s)}. \tag{3}$$

For transformation processes analysis, transfer function is revised accordingly, which according to introduced entropy approach changes characteristics in complex object "state – process – state" constitute information, proceeding from the following: arbitrary processes function is characterized by "deep" excellent values, that is $S \to -\infty$, but for reverse process $S_{\text{rv.p}} \approx W_{\text{rv.con}}(s) \to 0$.

In transition to change factors analysis and their relationship according to elements interaction within system it is expedient to use information transfer characteristic from one concept to another using Maison formula, which is dynamics assessment and at the same time reliability (as ability to transmit external influence / information and remain structured entities) systems:

$$K_{jl} = \frac{\sum_s P_s D_s}{D}, \tag{4}$$

where K_{jl} – transfer rate from some source j to l-th vertex graph; D – general graph determinant, similar to main determinant equations system describing system elements; P_s – information transfer (or direct process probability as arbitrary in interaction entropy terms) s-th through path from source j to l-th vertex graph; D_s – an algebraic complement to certain s-th through path.

In turn, $D, D_s,$ and P_s are determined by such rules.

Values D, D_s reflect transmission by graph contours, taking into account all contours, contiguous and discontiguous contours, namely for D.

$$D = 1 - \sum_r L_r^{(1)} + \sum_r L_r^{(2)} \sum_r L_r^{(3)} + \ldots, \tag{5}$$

where $\sum_r L_r^{(1)}$ – transfers sum along all r graph contours; $\sum_r L_r^{(2)}$ – products sum of all passon combinations for two discontiguous contours; $\sum_r L_r^{(3)}$ – the same for three discontiguous contours, etc.

Algebraic supplement D_s is determined by the formula (4) and by the same rules only taking into account discontiguous contours (which have no common vertices) with s-th through path.

Transmission P_s is one of all transfer product variants between intermediate vertices from j-th sources to l-th (finite) vertex:

$$P_s = \prod_j^{i-l} a_{ji}, \tag{6}$$

where a_{ji} – transfer from j-th to i-th structural element in the contour, graph.

Similarly, transmissions along contours L are determined.

As an example of topological models calculations, consider graph on Fig.1. The graph has only one cross-sectional path from initial vertex to finale and three contours, all of which are faced with this through path. Two contours L_1, L_2 not facing with each other. Determining elements the total transmission coefficient are:

$$L_1 = -a_{12} \cdot a_{21}; L_1 = -a_{34} \cdot a_{43};$$
$$L_1 = a_{12} \cdot a_{23} \cdot a_{34} \cdot a_{41};$$
$$D = 1 - (L_1 + L_2 + L_3) + (L_1 \cdot L_2) =$$
$$= 1 - (-a_{12} \cdot a_{21} - a_{34} \cdot a_{43} + a_{12} \cdot a_{23} \cdot a_{34} \cdot a_{41}) +$$
$$+ (a_{12} \cdot a_{21} \cdot a_{34} \cdot a_{43});$$
$$P_{04} = a_{01} \cdot a_{12} \cdot a_{23} \cdot a_{34}; D_{04} = 1 .$$

Output data is entered into graph transfer formula (5) for determining coefficient value:

$$K_{04} = \frac{P_{04} D_{04}}{D} =$$
$$= \frac{a_{01} \cdot a_{12} \cdot a_{23} \cdot a_{34} \cdot 1}{1 - (-a_{12} \cdot a_{21} - a_{34} \cdot a_{43} + a_{12} \cdot a_{23} \cdot a_{34} \cdot a_{41}) + (a_{12} \cdot a_{21} \cdot a_{34} \cdot a_{43})} =$$
$$= \frac{a_{01} \cdot a_{12} \cdot a_{23} \cdot a_{34} \cdot 1}{1 + a_{12} \cdot a_{21} + a_{34} \cdot a_{43} - a_{12} \cdot a_{23} \cdot a_{34} \cdot a_{41} + a_{12} \cdot a_{21} \cdot a_{34} \cdot a_{43}}.$$

The general links orientation between system elements, structuring it in integrity with the realization of certain properties, should reflect whole process progress in converting inputs into outputs. The importance for maintaining a stable process is important for system stability. This is possible if composite elements are combined into closed contour with negative feedback. In general dynamic system physics reflects different connections and contours set that make up input, output, and itself process set – system core. The system's input and output are defined as multi-dimensional vectors $\overline{X}_{\text{input}}, \overline{X}_{\text{ouput}}$ Communications in system core, as elementary cores outputs, in totality made up system vector state $\overline{X}''_{\text{state}}$ which corresponds to generally accepted systems mathematical description.

For complex state and processes representation in analytical system proposed to provide system structure in structural entropy matrix form, which reflects elements state correspondence and processes direction in elements relatively other elements state.

In contrast to O. Long, dynamic system state is interpreted in following way: a stable / constant (persistant) system has formed elements, that is structured, hence its entropy equals to "0", otherwise matrix diagonal will be inconsistency value by state function or the situation uncertainty according to information entropy (local can reach its maximum of 0.38) [10, 11]; processes in system with support of its stable structure – "1", its negative consequences – "-1", with system maintenance in equilibrium, natural quality – "0" ("S_{ij}") (Fig.2).

$$S = \begin{array}{|c|c|c|c|}\hline 0 & S_{12} & \dots & S_{1N} \\ \hline S_{21} & 0 & \dots & S_{2N} \\ \hline \dots & \dots & \dots & \dots \\ \hline S_{N1} & S_{N2} & \dots & 0 \\ \hline \end{array} \qquad T = \begin{array}{|c|c|c|c|}\hline T_1 & 0 & \dots & 0 \\ \hline 0 & T & \dots & 0 \\ \hline \dots & \dots & \dots & \dots \\ \hline 0 & 0 & \dots & T \\ \hline \end{array}$$

$$S_{\text{syst}} = \begin{array}{|c|c|c|c|}\hline 0\left(S_{11} = T_1 = 1,-1\right) & 1\left(S_{12} = T_{12} = 0,-1\right) & \dots & 1\left(S_{1N} = T_{1N} = 0,-1\right) \\ \hline 1\left(S_{21} = T_{21} = 0,-1\right) & 0\left(S_{21} = T_2 = 1,-1\right) & \dots & 1\left(S_{2N} = T_{2N} = 0,-1\right) \\ \hline \dots & \dots & \dots & \dots \\ \hline 1\left(S_{N1} = T_{N1} = 0,-1\right) & 1\left(S_{N2} = T_{N2} = 0,-1\right) & \dots & 0\left(S_{NN} = T_N = 1,-1\right) \\ \hline \end{array}$$

Fig.2. *"Structure system matrix" and "action variaty matrix" given in view "structure entropy matrix of dinamic system"*

Main diagonal elements are the own operators of system dynamic parts (operating elements, in O. Lange terminology) $Q(s)$. On both sides of diagonal and on right side of matrix, operators are mapped $R(s)$ (see (2)), which are used for structural complex system formations studies.

System objects of natural and man-made content are defined as target-oriented complexes, which include aims namely – the base of research, analysis and evaluation, object state, input and output information resources, the object environment directly (Fig.3).

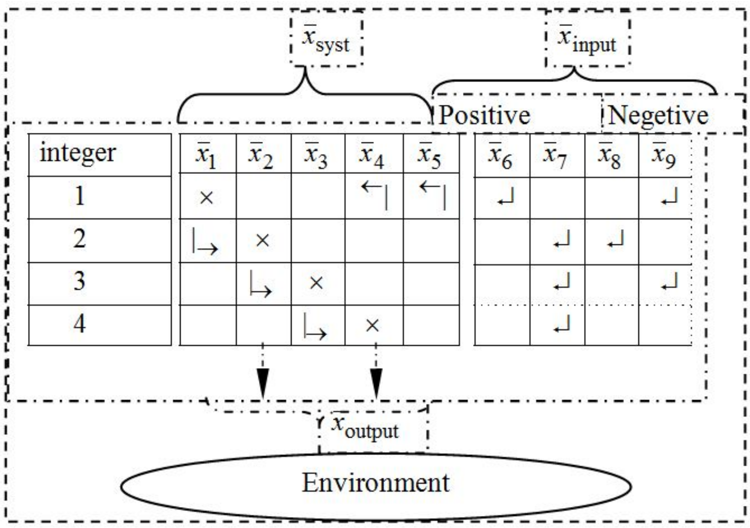

Fig.3. *Structure matrix "system – environment" according to given aims taking into account components and relations in system kernel*

In proposed complex systems research direction by information-entropy (entropy-information) approach with synergetic analysis elements (synergetics), the indicated division into groups [12] is associated with analyzed object division into 3 systems "(system-environment) – processes-external environment – system state" or socio-ecological-economic system, which is information input (socio-economic aspects), research system core (socio-economic elements) and environment (socio-ecologycal aspects – natural (ecological) systems state and men health).

According to this structural matrix form [12] is changes – input from the left as information flow components properties has an impact on the research structure core elements, the right output factors that have an impact on the external environment. Construction and analysis by such matrix complex system (object of research) state according to the information entropy is envisaged, which includes dynamic system entropy that is evaluation according to entropy function (state – process – state) and synergy with regard to the order establishment by the self – organizing mechanism of arbitrary processes.

It is proposed to modify and complete complex system research object analysis. According to observed data by received structural matrix, it is expedient to construct a model in graph form which have cognitive map content, that is the base of the factor analysis in relation to the systems dynamics and determination self-organization direction regarding the structurization of a stable systemic formation by influence factors – x_1, x_2, x_3, x_4 (first factors group) responsible $\bar{x}_{\text{input}} = \bar{x}_6, \bar{x}_7, \bar{x}_8, \bar{x}_9$ provided internal system structure functionality provision (x_1, x_2 – system development contributing, x_3, x_4 – negative impact) and system elements state, namely x_5, x_6, x_7, x_8, x_9 (second group) are relevant $\bar{x}_{\text{syst}} = \bar{x}_1, \bar{x}_2, \bar{x}_3, \bar{x}_4, \bar{x}_5$, and action factors on external environment by system side $\bar{x}_{\text{output}}$ (third factors group) positive character x_{10} (system performance) and negative impact in form of waste x_{11} (Fig.4).

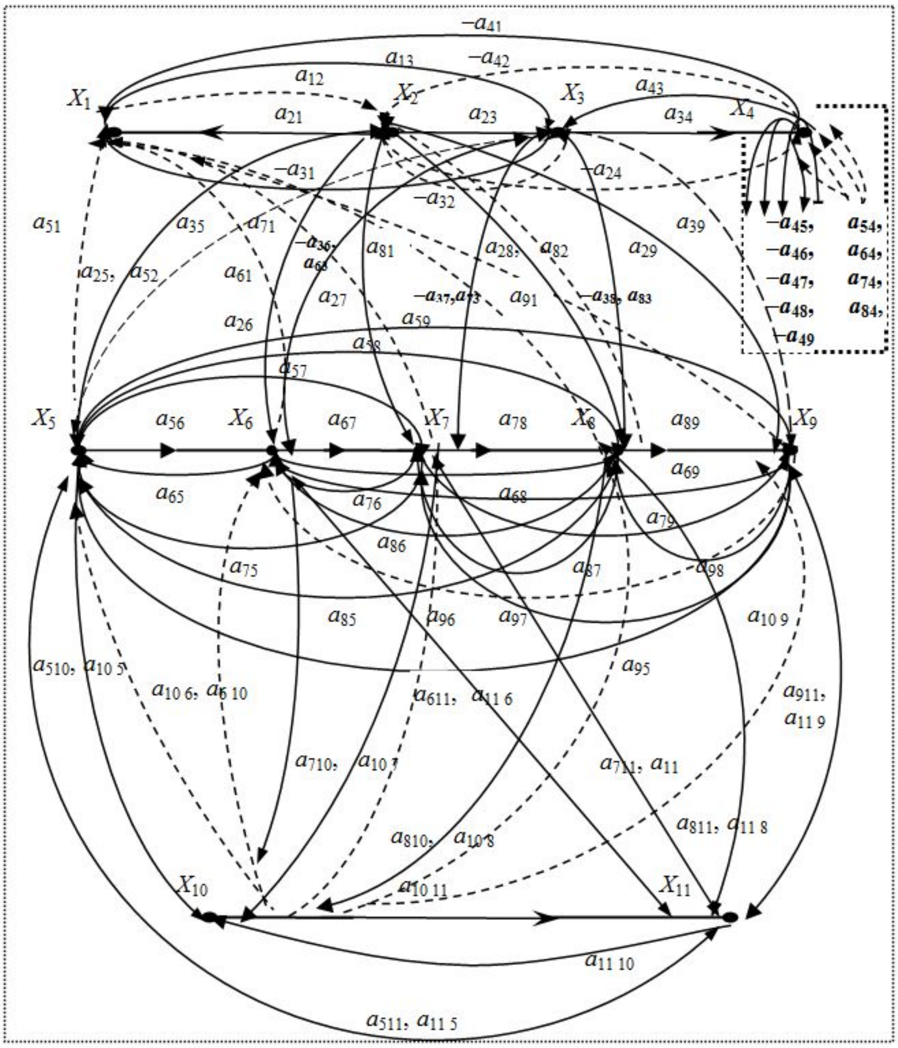

Fig.4. *Schema of system object graph model – oriented graph $G = G(X, A)$: X – set of analized systems: X_1, X_2, X_3, X_4 – environment recourses; climate; socio-economic environment; transport; X_5, X_6, X_7, X_8, X_9 – state of atmosphere; hydrosphere; soil; flora, fauna; X_{10} – man state; X_{11} – external ecological environment; A – connections between systems a_{ji} where i – information entrance system, j – information exit system*

According to internal link data between parameters / properties $X\{x_i\}$ object components (external influence systems – investigated object system – target identification systems (initial influences reception systems)) determine system object mathematical model:

$$a_{ii}x_j = \sum_{i=1, j\neq l}^{l} a_{ji} \cdot x_j \, (i = 1, 2, ..., n) . \qquad (7)$$

Depending on harmful effects intensity on given approaches to modeling, "environment – system – environment" can roughly calculate the decline in human health, population and, consequently, its social impact reduction. The negative influence of external environment on reproductive function is expressed in its functionality decrease or defective offspring appearance due to gametes mutation, fetal developmental disorders, neuroendocrine transformation in body due to stress (Fig.5).

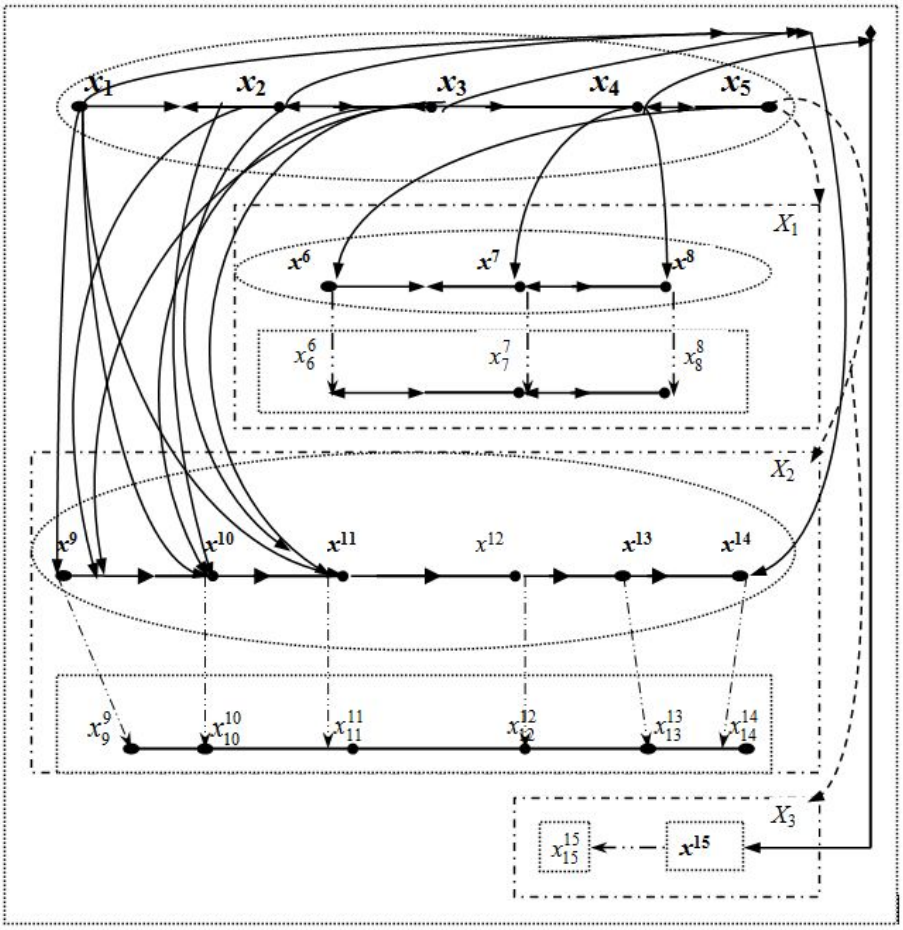

Fig.5. *Systems object graphical model schema – topological-cognitive model of object "organism = (environment – systems) – functionality – object state":→ – material and energy connections between system elements; – → – data transmission about general influence of factor physical activity on system*

Thus, state and processes analysis and evaluation in system object developed for study due to attracted methodological support system for consistent problem tasks solution, evaluation task solution in uncertainty conditions allows to obtaine results on a strict object base according to proposed combination of complex and system approaches into a single whole.

4. CONCLUSIONS

1) To determine object systems transition dynamics to co-operative coherence to achieve synergistic realization set target point of positive states and stable functionality is proposed to use graph models of natural and man-made objects for "state (system – environment) – process – system state" research.

2) Highly structured system "object – environment" state assessment (see Figures 4, 5) and risk-free solution adoption for stabilizing component systems, obtaining new systems properties, development for target system used subject area conceptual models in structural matrix form of complex systems ("object – environment") with knowledge-oriented databases development, which are based on research methods, knowledge, information systems, namely structural matrix "organization – process (functionality)", "information structure – functionality", "organization – knowledge-oriented information structure".

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ИСПОЛЬЗОВАНИЕ ГРАФ-АНАЛИТИЧЕСКИХ МЕТОДОВ МОДЕЛИРОВАНИЯ СИСТЕМНЫХ ОБЪЕКТОВ ДЛЯ ОПРЕДЕЛЕНИЯ ИНТЕГРИРОВАННОЙ ОЦЕНКИ ИХ СОСТОЯНИЯ

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Определено состояние объекта при исследовании "система – среда", основанное на системном граф-аналитическом моделировании для представления реальных связей и отношений между любыми системами в природе. Обоснованное нестандартное решение по прогнозным состояниям и изменениям приводит к состоянию "системы – среды", основанному на построенных когнитивных моделях и анализе энтропии для оценки устойчивости направления деятельности и реализации ситуации. Практическое использование систематической методологической поддержки комплексных объектов комплексного исследования базируется на последовательном анализе моделей графов. Для анализа физических процессов смещения между простыми компонентами идеальной системы, которые являются источниками потенциальной и кинетической энергии, изменения его мощности через накопление вещества или энергии, используется структурная граф-топологичная модель физических процессов.

ВИКОРИСТАННЯ ГРАФ-АНАЛІТИЧНИХ МЕТОДІВ МОДЕЛЮВАННЯ СИСТЕМНИХ ОБ'ЄКТІВ ДЛЯ ВИЗНАЧЕННЯ ІНТЕГРАЛЬНОЇ ОЦІНКИ ЇХНЬОГО СТАНУ

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Визначено стан об'єкта при дослідженні "система – середовище", заснований на системному граф-аналітичному моделюванні для представлення реальних зв'язків та відносин між будь-якими системами в природі. Обгрунтоване нестандартне рішення за прогнозними станами та змінами призводить до стану "системи – середовища", що базується на побудованих когнітивних моделях та аналізі ентропії для оцінки стійкості напрямку діяльності та реалізації ситуації. Практичне використання систематичної методологічної підтримки комплексних об'єктів комплексного дослідження базується на послідовному аналізі моделей графів. Для аналізу фізичних процесів зміщення між простими компонентами ідеальної системи, які є джерелами потенційної та кінетичної енергії, зміни його потужності через накопичення речовини або енергії, використовується структурна граф-топологічна модель фізичних процесів.