Methodology of Formation of the Attribute Structure of the Natural-Technical System

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Abstract. Based on the system analysis of the development and implementation of the geoinformation approach to managing the development of systems, the article presents the scientific and methodological foundations of the target ontology of the geoinformational space of control and proposes a method for determining the optimal compromise weight coefficients expressing a generalized expert opinion.

1. Introduction

The geoinformation approach to managing the development of systems allows us to single out the elements of the system as the corresponding components of the geospace of solutions - objects and their states, factors, situations. The target ontology of the geoinformation space for managing the development of systems within socio-economic systems and territories can be represented as a semantic network of the following entities (objects):

- natural-technical system (NTS) - an integral, spatially-ordered set of interacting natural, technical and organizational subsystems. NTS border with each other or intersect, influence each other (interact in the process of functioning);
- territory - an area of the natural environment interacting with natural and technical systems, in most cases does not have discontinuities, it is a connected area of space;
- population as a subject and object of government in terms of democratic principles of government.

In the process of developing and implementing a solution, an assessment of its quality must be performed, which implies the definition of entities, subjects and objects of management and decisions on its development. Analysis of the state of objects in the phase space and the formation of attributive models involves assessing their structural and functional characteristics, as well as the characteristics of the system of connections in the internal and external environment of the NTS and the territory.

The generalized structure of the natural-technical system includes (Fig. 1):

- natural subsystem as a self-organizing subsystem;
- technical (organizational and technical) subsystem is a managed object;
- a control system that includes a control subject (target subsystem) and a monitoring subsystem that provides information to the control system;
- control factors (material, energy and information flows);
- result streams (products of NTS activity).

Figure 1. Generalized structure of the natural-technical system.

2. Research materials and methods
To solve the problems of managing the NTS can be considered within several categories (the ontology of the NTS, Table 1).

The analysis of system characteristics is one of the most significant stages in the development of a strategy for managing the development of systems, which makes it possible to formalize the links between knowledge bases and geodata.

Each natural and technical system is characterized by certain properties that ensure its quality, i.e. the quality of the system should be considered as a set of properties of the system, ensuring its suitability for use as intended [1-7]. If each of the properties of the system can be described quantitatively using the corresponding variable, the value of which characterizes the measure (intensity) of its quality relative to this property, we obtain that the quality level of the system is characterized by a set of indicators of its essential (attributive) properties, which can be represented in the form of a vector, the components of which are indicators of system attributes. The dimension of the vector is determined by the number of attributes (essential properties) of the system. Relationships can exist between individual attributes. And then, the required quality of the system, as the goal of managing its development, is set by the conditions that the possible values of the indicators of the attributes of the system should have - the criteria for the effectiveness of the decisions made. We denote:
- set of input actions (inputs) of the system \(-x=(X_1, X_2, \ldots, X_n)\), and their entire admissible set \(x \in \bar{X}\);
- set of output actions (outputs) of the system \(-y=(Y_1, Y_2, \ldots, Y_m)\), and their entire admissible set \(y \in \bar{Y}\);
• a set of parameters (attributes) characterizing the properties of the system, constant at all time of consideration, and affecting the output effects of the system – \( a = (A_1, A_2, \ldots, A_k) \), and their entire admissible set \( a \in \bar{A} \)

### Table 1. Characteristics of NTS categories.

| Characteristic                  | Elementary | Local | Regional | Global |
|--------------------------------|------------|-------|----------|--------|
| **Sub-system components**      |            |       |          |        |
| Homogeneous in relation to natural processes. Make up a connected area of limited space | Spheres of interaction of elementary PTS. Inhomogeneous in relation to natural processes. Make up a connected area of space (territory of the enterprise and adjacent territories) | Areas of interaction of local PTS, natural geo-systems and territories. Inhomogeneous in relation to natural processes. The set of interaction areas does not form a connected area of space | Surface of the Earth, natural geosystems and territories. Inhomogeneous in relation to natural processes. The set of interaction areas does not form a connected area of space |
| Interactions                   | Direct     | Mostly direct and partly indirect (organizational) | Mostly indirect (organizational and institutional), natural disturbing | Mostly indirect (organizational, institutional, contractual), natural disturbances |
| Exogenous processes            | Technogenic | Technogenic, partly ecological | Mostly technogenic, in some areas within the boundaries of regional NTS - environmental | Mostly technogenic, in some areas - environmental |
| NTS boundaries                  |            |       |          |        |
| Conditional, established based on the results of engineering calculations (projects) Identical within the entire NTs (transitional or relatively stabilized) | Combinatorial; in the general case - the envelope of the outer boundaries of elementary NTs located in a certain territory Various in accordance with the state of individual elementary NTs. In general - the mode of relative stabilization | Combinatorial, set taking into account the boundaries of interaction within the territory | Combinatorial, set taking into account the boundaries of interaction within the geosystem |
| Functioning mode               |            |       |          |        |
| Different                       |            |       |          |        |
| Methods for forecasting the functioning of the NTs Control system (operation) of the structure, technical system | Deterministic | Stochastic and deterministic | Stochastic | Stochastic |
| Organizational structure of NTs | Management system of the organizational and technical system (organization, enterprise) | Management system of a region, city, municipality, territory | System of international relations |
a set of parameters (attributes) characterizing the properties of the system that change during consideration (system state) - \( z = (Z_1, Z_2, ..., Z_l) \), and their entire admissible set \( z \in \tilde{Z} \);

independent parameter (s) of the process in the system – \( t \) and their entire admissible set - \( t \in \bar{T} \);

the rule \( S \) (function, operator) determination of system state parameters by inputs, constant parameters and process parameter \( z = S(x, a, t) \). This record means finding parameters according to this rule (and not about the value \( z \));

the rule \( V \) (function, operator) determining the output characteristics of the system by inputs, constant parameters, process parameter and system state parameters \( y = V(x, a, t, z) \);

the rule \( \bar{V} \) (function, operator) determination of the output characteristics of the system by inputs, constant parameters and process parameter \( y = \bar{V}(x, a, t) \). The specified rule can be obtained by rule substitution \( S \) as a rule \( \bar{V} \), which excludes state parameters from it. Based on the introduced designations, parameters and rules, the system model can be written as a tuple (a set of ordered collections of elements):

\[
\sum : \{x, y, z, a, t, S, V, \bar{V}\}, \quad x \in \bar{X}, \quad y \in \bar{Y}, \quad a \in \bar{A}, \quad z \in \bar{Z}, \quad t \in \bar{T}
\] (1)

In accepted terms, system quality indicators:

- a set of parameters (attributes) characterizing the properties of the system, constant during the entire time of consideration, and affecting the output effects of the system – \( a = (a_1, a_2, ..., a_k) \), and their entire admissible set \( a \in \bar{A} \);

- a set of parameters (attributes) characterizing the properties of the system that change during consideration (system state) - \( z = (Z_1, Z_2, ..., Z_l) \), and their entire admissible set \( z \in \bar{Z} \).

The system quality vector can belong to one of the classes:

- suitability for the intended use;
- optimality in accordance with the accepted criterion;
- superiority in quality of all other studied systems.

Moreover, the criterion of suitability is dominant and universal. Optimality and superiority criteria should be considered as private. In such a setting, the goal of the system's development is to achieve the required level of its quality, which will ensure the required level of its efficiency. Efficiency is considered as a complex operational property of the system, which characterizes its adaptability to the achievement of the set goal (performance of the task facing the system).

Method of forming the structure of object attributes. An analysis of the process of applying a natural-technical system allows us to conclude that the attribute characteristics are not equal at various stages of the system's functioning. This leads to the need to form the structure of properties (attributes) of control objects.

3. Research result

Let the NTS function in \( m \) situations \( C_i \), \( i = 1, ..., m \). Depending on the situation, the NTS is characterized by a number of priority properties (attributes) \( I_i = \{1, 2, ..., n\} \) and a priority vector \( V_i = \{v_{i1}, v_{i2}, ..., v_{in}\} \). A number of priorities is an ordered set of properties (attributes) and reflects a qualitative domination relation, the components of which \( v_{iq} \) are binary priority relations that determine the degree of superiority in significance of two neighboring properties (attributes) \( P_{iq} \) and \( P_{iq} + 1 \), \( q = 1, ..., n \) from the series priority \( I_i \), and the value \( v_{iq} \) shows how many times the property
$P_{iq}$ is more important than another property (attribute) $P_{iq} + 1$. If properties (attributes) are equal $v_{iq} = 1$. For the convenience of calculations, we can put $v_{in} = 1$. Vector $V_i$ is determined as a result of pairwise comparison of properties (attributes) $P_{ij}, i = 1, ..., m, j = 1, ..., n$, pre-ordered according to a number of priorities $I_i$.

Having vectors $I_i$ and $V_i$ as initial data for all typical situations $C_i$, it is possible for each of them to determine the vector of weight coefficients $\Lambda_i = \{\lambda_{i1}, \lambda_{i2}, ..., \lambda_{im}\}$, which is an n-dimensional vector, where its components are related by the relations $0 \leq \lambda_{iq} \leq 1, q = 1, ..., n; \sum_{q=1}^{n} \lambda_{iq} = 1$. The components $\lambda_{iq}$ of the vector $\Lambda_i$ have the meaning of weight coefficients that determine the relative superiority of the $q$-th property over the others. They are found using addition

$$\lambda_{iq} = \frac{\prod_{k=1}^{n} v_{ik}}{\sum_{q=1}^{n} \prod_{k=1}^{n} v_{ik}}, \; q = 1, n, \; i = 1, m. \quad (2)$$

As a result of calculating the values of the weight coefficients for each typical situation of the NTS functioning, a matrix of the form

$$\Lambda = \begin{bmatrix}
\lambda_{11} & \lambda_{12} & ... & \lambda_{1n} \\
\lambda_{21} & \lambda_{22} & ... & \lambda_{2n} \\
\cdots & \cdots & \cdots & \cdots \\
\lambda_{m1} & \lambda_{m2} & ... & \lambda_{mn}
\end{bmatrix}, \quad (3)$$

Where $\lambda_{ij}$ is the weight of the $j$-th property in the $k$-th typical situation of the NTS functioning.

In order to form the structure of properties (attributes) of the NTS, taking into account various typical situations of its functioning, it is necessary to obtain generalized weights $\lambda'_j, (j = 1, ..., n)$ of each property (attribute), which most fully take into account the information contained in the matrix $\Lambda$.

This problem can be solved on the basis of the entropy approach to finding the significance of properties (attributes), based on the conditions of the NTS functioning. Based on the data of the matrix $\Lambda$, the level of entropy of each property (attribute) is determined

$$H_j = -\frac{1}{m} \sum_{i=1}^{m} \lambda_{ij} \ln \lambda_{ij}, \quad (i = 1, m, j = 1, n) \quad (4)$$

Since $0 \leq H_j \leq 1 \; (j = 1, n)$, we can find the level of variability of the $j$-th property (attribute) within the considered situation

$$d_j = 1 - H_j (j = 1, n) \quad (5)$$

Then the generalized expert estimates of the weights of properties (attributes) can be calculated by the formula

$$\alpha_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, \; (j = 1, n), \quad (6)$$
which is valid provided that all situations are considered a priori equally significant, i.e. there are no expert assessments of their priority. If these estimates are known $\alpha_j$, then it is advisable to find the complex significance

$$\lambda_j^* = \frac{\alpha_j}{\sum_{j=1}^{n} \alpha_j}, \quad j = \overline{1, n}$$  \hspace{1cm} (7)

here the vector $\alpha = \{\alpha_1, \alpha_2, \ldots, \alpha_n\}$ can be determined from the matrix of expert assessments of each situation. If we conduct a group examination, in which each of the $s$ members of the commission assigns his own values of the coefficients that satisfy the conditions

$$\sum_{j=1}^{n} \alpha_{kj} = 1, \alpha_{kj} \geq 0, \quad j = \overline{1, n}, \quad k = \overline{1, s}$$ \hspace{1cm} (8)

then the result will be a matrix of expert assessments

$$A = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \cdots & \alpha_{1n} \\ \alpha_{21} & \alpha_{22} & \cdots & \alpha_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \alpha_{m1} & \alpha_{m2} & \cdots & \alpha_{mn} \end{bmatrix}$$ \hspace{1cm} (9)

where $\alpha_{kj}$ is an expert assessment of the relative importance of the $j$-th situation, proposed by the $k$-th expert.

To determine the optimal compromise weight coefficients $\alpha^*$, expressing a generalized opinion, a compromise $F(A, \alpha^*)$ is set and the extremal problem is solved

$$F(A, \alpha^*) = \min_{\alpha \in D} F(A, \alpha)$$ \hspace{1cm} (10)

where the vector $D$ has the following form

$$D = \{\alpha[\sum_{j=1}^{n} \alpha_j = 1, \alpha_j \geq 0, \quad j = \overline{1, n}]\}$$ \hspace{1cm} (11)

This technique is a search for some measure of closeness between an arbitrary vector $\alpha \in D$ and elements of the matrix $A$. As a measure of closeness $F(A, \alpha^*)$, the well-known quadratic function

$$F(A, \alpha^*) = \sum_{k=1}^{s} \sum_{j=1}^{n} (\alpha_{kj} - \alpha_j)^2$$ \hspace{1cm} (12)

Then the optimal solution to problem (7) is the vector of mean values over the elements of the columns of the matrix $A$

$$\alpha_j^* = \frac{1}{s} \sum_{k=1}^{s} \alpha_{kj}, \quad j = \overline{1, n}$$ \hspace{1cm} (13)

The resulting vector of weight coefficients $\lambda^* = \{\lambda_1^*, \lambda_2^*, \ldots, \lambda_n^*\}$, is used as initial information to form the hierarchical structure of the NTS attributes.

4. Conclusions

The geoinformation approach to managing the development of special-purpose systems makes it possible to single out the elements of the system as the corresponding components of the geospace of solutions - objects and their states, factors, situations. The target ontology of the geoinformation space...
for managing the development of special-purpose systems within socio-economic systems and territories can be represented as a semantic network of the following entities (objects): natural and technical system, territory, population. Analysis of the state of objects in the phase space and the formation of attributive models involves assessing their structural and functional characteristics, as well as the characteristics of the system of connections in the internal and external environment of the NTS and the territory, which can serve as indicators of the quality of systems and are used for geoinformation control of them. development. For the formation of a hierarchical structure of attributes of objects of geoinformational control, a method has been developed for determining the optimal compromise weight coefficients expressing a generalized expert opinion.

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Acknowledgments
The work was carried out at the Russian State Hydrometeorological University within the framework of the State assignment of the Ministry of Science and Higher Education of the Russian Federation, project No. FSZU-2020-0009.