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ZASTOSOWANIE STRUKTURALNO-GRAFICZNEGO I GIS MODELOWANIA W BADANIACH KARTOGRAFICZNYCH

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Streszczenie. Omówiono modelowanie strukturalne i graficzne: koncepcje, połączenia, klasyfikacja i zastosowanie w badaniach kartograficznych. uzasadnione jest użycie modeli strukturalno-graficznych do badania obiektu mapowania. strukturalno-graficzne funkcje modelowania są zdefiniowane. badane jest modelowanie przestrzenne i typy modeli przestrzennych świata rzeczywistego.

Słowa kluczowe: mapowanie, model strukturalno-graficzny, mapa, gis-modelowanie, funkcje gis-modelowania.

APPLICATION OF STRUCTURAL-GRAPHICAL AND GIS-MODELING IN CARTOGRAPHIC RESEARCH

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Abstract. Structural-graphic modeling is considered: concept, connections, classification and application in cartographic research. The principles of modeling in cartography (the possibility of using maps using common epistemological categories;

the use of general scientific methods of modeling and rational forms and variants of contacts with other types of modeling; the etymology of the term indicates the place of cartographic modeling as a means of research in the general system of cognition).

The functions of structural-graphical modeling are defined. Functions of structural and graphical modeling are determined, and they are investigated, which allow: to carry out selection of existing maps necessary for research; identify elements of systems that have not yet been mapped; determine the topic of maps and their placement within the complex cartographic works; use maps of other elements of the system when creating a series of maps of each specific element; ensure that the maps of this element are those of other elements; change the complex maps and their groups; determine the main columns of tables for collecting information in relational or electronic databases; identify sections of map legends; present legends in the form of graphical link models of lower-ranking system elements.

Spatial modeling is investigated, the types and models of real-world spatial models are substantiated and identified, in particular: analogue and digital models; discrete and continuous models; individual and aggregate models; static and dynamic models; cellular vending machines; agent models.

Keywords: map, structural-graphic model, mapping, GIS-modeling, GIS-modeling functions.

ЗАСТОСУВАННЯ СТРУКТУРНО-ГРАФІЧНОГО ТА ГІС МОДЕЛЮВАННЯ У КАРТОГРАФІЧНИХ ДОСЛІДЖЕННЯХ

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Анотація. Розглянуто структурно-графічне моделювання: поняття, зв’язки, класифікація та використання у картографічних дослідженнях. Визначено принципи його моделювання в картографії (можливість використання карт за допомогою загальних гносеологічних категорій; використання загальнонаукових методів моделювання та раціональні форми і варіанти контактів з іншими видами моделювання; етимологія терміна вказує місце картографічного моделювання як засіб дослідження в загальній системі пізнання).

Обґрунтовано використання структурно-графічних моделей для дослідження об’єкта картографування. Визначено функції структурно-графічного моделювання, досліджено, що вони дають змогу: провести підбір існуючих карт,

необхідних для дослідження; виявити елементи систем, які ще не отримали відображення на картах; визначити тематику карт і їх розміщення в межах комплексних картографічних творів; використати карти інших елементів системи при створені серії карт кожного конкретного елемента; забезпечити відповідність карт даного елемента картам інших елементів; встановити зміну комплексних карт і їх груп; визначити основні графи таблиць для збору інформації у реляційних чи електронних базах даних; визначити розділи легенд карт; подати легенди у вигляді графічних моделей зв'язків елементів системи нижчих рангів.

Досліджено просторове моделювання, обґрунтовано та визначено типи просторових моделей реального світу, зокрема такими є: аналогові й цифрові моделі; дискретні й безперервні моделі; індивідуальні й агреговані моделі; статичні й динамічні моделі; клітинні автомати; агентні моделі.

Ключові слова: картографування, структурно-графічна модель, карта, ГІС-моделювання, функції ГІС-моделювання.

The conceptual basis and problem orientation of research is the basis for understanding the mapping object. At the pre-cartographic stage, a systematic approach in conjunction with simulation methods is used to study the objects being investigated. This is the provision of a separate scientific methodology of cartography, developed at the Institute of Geography of the National Academy of Sciences *(Rudenko 1992, p.33).* Among the theoretical and methodological provisions involved in the research, the main ones were: the multi-dimensional concept of the model, types of modeling, their relationships, especially the connections of structural-graphic and cartographic modeling.

The model (in the broadest sense) is an image (including conditional or imaginative ones), a depiction, a description, a schematic diagram, a drawing, a graph, a plan, a map, etc., or a prototype (sample) of any object or object system ("the original" of this model), which in scientific research are used to replace the original system for the purpose of studying *(BSE 1971).*

Based on this term definition, to a certain extent one can assume that the description of the original system is a verbal model; a diagram, a drawing, a graph is a graphic model; plan, map, and other geo images are a mapping model. Studying complex objects on models is understandable. As Chorafas D. noted, the normal human reaction to the apparent complexity of the environment is building for oneself a simplified and understandable picture. "Next, one seeks to replace this model with the real world of our experience and thus gain a victory over it" *(Chorafas 1965, 167).*

Another scientist notes that our mind decomposes the real world into a number of simpler systems, which makes it possible immediately to "examine the essential features of the whole" *(Apostel 1961, p.1-37).* So the model is a simplified reproduction of reality, it reflects in its general form its essential features and interconnections.

Skilling H. (Skilling 52, 338A-396A) affirms that the theory, and the law, and the hypothesis, and the idea, which is inherent in a certain structure, as well as the role, correlation, equation or data synthesis, can be a model. For mapping, it is especially important that models can be considered as judgments about the real world, which are formed through the consideration of objects in space (spatial models) and in time (historical models).

As noted by O. M. Berlyant *(Berliant 1986, p.240)* and T. I. Kozachenko, G. O. Parkhomenko *(Kozachenko 1999, p.328)*, the introduction of the concept and principles of modeling in cartography is useful in many respects. First, it makes it possible to characterize cartography and use of maps with the help of general epistemological categories. Secondly, the use of general scientific principles of modeling allows you to enter maps into a large class of models, expand, supplement and correct mapping methods, linking them with general scientific methods of modeling. There is a possibility to find rational forms and variants of contacts with other types of modeling and with other models (mathematical, aerospace, etc.). Thirdly, the etymological certainty of the term precisely indicates the location of cartographic modeling as a means of research in the general system of cognition, gives an idea of the set of properties of the map as a model.

Thus, the use of the term "cartographic modeling" is appropriate and justified from the epistemological point of view, from the standpoint of the methodology and methodology of cartography and its terminology

As the cartographic modeling, we understand the creation, analysis and transformation of cartographic works as models of real objects and processes for the purpose of their use to acquire new knowledge about these objects and processes.

In the sciences about the Earth and the society, modeling is not only a method or a means, but a research style supported by the mapping method.

In the Earth sciences, that model suspension is not less by the chi method, but by the style of precedence for the additional cartographic method. *As the style of cartographic research O. M. Berlyant understands the stable integrity or unity of a figurative system of reflection of an object in a geospace, which contains logically interconnected images of an object, embodied in various types of models (Berliant 1986, 240).* Such a statement is consistent with the studied classifications of models.

Models are divided into two broad categories: material (real) and ideal. Material models, similar to the original system, are divided into spatial, physically and mathematically similar, and ideal - figurative (iconic), figurative-sign and sign (symbolic) ones *(Rudenko 1991, p.212).* P. Haggett and R. Chorley *(Chorley 1971, p.380)* distinguish models depending on material nature: real (including experimental), theoretical, symbolic, conceptual and thinking. Among the material ones, reproductive and analogue are distinguished.

Proposed by A. D. Armand classification of models of natural territorial complexes is suitable for the characterization of cartographic models. The author divides the model by purpose and construction logic, the degree of reflection of the dynamics and the use of numerical material, by the nature of the implementation, taking into account random deviations and the physical essence of the modeled object. This classification is known to be used for determining the varieties of cartographic models *(Kozachenko 1999, p.328).* One date maps or series of cards are considered as static models, time-varying maps – as kinematic models, and maps that characterize the movement of phenomena or the development of processes in time and space - as dynamic models. The arguments were given that there are maps reflecting exchange of substance, energy and information.

We believe that the authors *(Kozachenko 1999, p.328)* were not so much aiming to present the classification of cartographic models, but rather paving the way for the search for a system of map signs as models. O. M. Berlyant believes that the cartographic models can be divided by accuracy into precise and approximate ones, by time into retrospective, modern and predictable ones, by the degree of generalization of information into analytical, complex and synthetic ones *(Berliant 1986, p.240).* Searching for classification marks is useful not only for ordering maps classifications as models, but, first of all, for identifying common features with other types of models, and using the latter as auxiliary ones in the process of cartographic research of the objects not yet displayed on the map.

The practice of cartographic research has proved the usefulness of the application of auxiliary structural and graphical models in the transition from verbal models (verbal descriptions of objects to be mapped) and informative (information about the object presented in the form of tables, which indicates the links of the object in geospatial and its qualitative and quantitative characteristics) to cartographic ones.

It is known that first the term "graphic model" was used and then was introduced into the scientific literature by I. Guseva and Yu. G. Saushkin *(Guseva 1968, p.17-50)*. In the further studies of Ukrainian scientists, the term "structural and graphic model" *(Kozachenko 1999, p.328)* was substantiated, which we give preference to over the term "constructive-logical model", introduced in the literature later by I. Yu. Levytsky and VA Peresadko *(Levitsky 1988, p.14)*, because the latter lacks guidelines for the implementation of the model, which presents the structure of the object in the graphical form of the elements (blocks) of the original system and the lines of internal and external connections connecting the blocks.

Creating any cartographic works requires the study of literary sources describing the territorial systems to be mapped. *Structural graphic models serve as an intermediate between the verbal description of real systems (verbal models) in literary sources and cartographic models.*

They are inherent in such a basic property of any model as a scale of complexity, which manifests itself in reflecting the structure of real systems. Structurality is a specific feature of structural-graphic models.

The scale of space in the structural and graphical model is reflected in the selection of elements of systems and subsystems in relation to a specific territory, and the scale of time - in the set of elements of systems that characterize the stages of development of the original system in a certain time interval.

To understand the suitability of structural and graphic models in cartographic studies, it is important to classify them as proposed by the authors of the monograph *(Kozachenko 1999, p.328)* and the methodical features of their construction.

Consideration of theoretical foundations and the experience of creating various structural and graphic models of systems of various objects, has made it possible to recognize that the functions of structural-graphic models have a very significant value for cartographic modeling, namely:

- to select the existing maps needed for research;
- to identify elements of systems that have not yet been mapped and to determine the need for new maps to display the essential properties and connections of objects;
- to define the themes of maps and their placement within complex cartographic works;
- to use maps of other system elements when creating a map series for each particular item;
- to ensure that this item maps correspond to other elements' maps;

- to identify the change of the complex maps and their groups;
- to define the main columns of the tables for gathering information in relational or electronic databases;
- to define sections of maps' legends, that is, create models of unified legends of typical maps;
- to submit legends or their separate sections as graphic models of connections of elements of the system of lower ranks.

Geographic information systems also model our world. All GIS are built on the basis of formal models that describe the placement of objects and processes in space. The geographic models of our world form the informational basis of GIS analysis. The models are useful and used in a wide range of GIS applications from a simple evaluation to predicting the future of a complex research object. In the past, modeling was often needed in conjunction with GIS with special software designed to function in the field of dynamic modeling. Modeling in GIS raises a number of important issues, including the question of scaling, accuracy, and designing infrastructure objects to facilitate the exchange of models.

The term *"modeling"* is used in several different contexts in the field of GIS, so it is advisable to clarify the meaning. There are two particularly important meanings:

- the data model is defined as a set of data expectations - a template in which data necessary for a particular application can be inserted. For example, a table is a very simple example of a data model; The rows of the table correspond to a group or class of real possibilities such as counties, lakes or trees, and columns correspond to different characteristics of objects, in other words, attributes. This template table will be very useful as it provides the optimal coincidence of data in many GIS applications. Essentially, GIS data models allow the user to create an idea of how the world looks.

- the model (without qualification data) is the representation of one or more processes that are believed to occur in the real world, in other words, about how the world is organized. A model is a computer program that accepts a digital representation of one or more aspects of the real world and converts them to create a new representation.

In the complex approach it is necessary to distinguish between the following types of geographic models of the real world: *analog and digital models; discrete and continuous models; individual and aggregated models; static and dynamic models; cellular automata; agent models.*

Analog models are the most common type. An analog model is defined as a large-scale model, representation of the real-world system, in which each part of the real system is modeled in miniature. Very popular analog models of the real world are paper topographic, geographic and thematic maps. The success of analog models depends on the degree of system expansion, because the work of the system on the scale of the model is identical to the work of the real system.

In *digital or calculating model*, all operations are carried out using a computer. Data is collected in the data model and encoded using different coding schemes that reduce the relevant aspects of the real world to structures of zeros and ones (units). The model itself is also encoded in the same limited alphabet as a computer program or software. Digital models do not have a representative faction, because there is no distance in the model compared with the distance in the real world. Instead, the level of geographic detail is fixed by the spatial resolution or the size of the smallest spatial object represented in the database.

In addition to *spatial resolution, time resolution* is also important in dynamic models, since it determines the length of the model's time step. Any dynamic model comes from a discrete sequence of such steps, each of which represents a certain period of time, because the program tries to predict the state of the system at the end of the time step based on the input in the beginning of the time step. Spatial and temporal separations should correspond to the real nature of the simulated process.

Discrete models imitate the processes that occur between discrete entities, such as the forces acting between celestial bodies and controlling their movement, or the behavior of humans or animals when they interact in space. In the concept of discrete objects, the geographic space is empty except when it is occupied by point, linear or plane objects that can overlap each other, not necessarily using free space, and it is impossible to determine their number. The concept of discrete objects works best when describing and presenting biological organisms or spatial objects created by human activity such as buildings, vehicles, or fire hydrants.

Continuous models, on the other hand, are models in terms of variables that are continuous space functions, for example, atmospheric pressure or temperature, soil acidity or humidity. The concept of a continuous field describes the geographic world with a series of continuous maps, each of which represents the changes of a definite variable over the surface of the Earth. There are no spaces in the cover: there is only one value for each variable in each place. Continuous field models, as a rule, express the knowledge of the work of the physical system in terms of partial derivatives of differential equations that connect the meaning, the level of change in time, spatial gradients and spatial curvature in continuously varying quantities.

Individual models. In principle, you can model any system with a set of rules on the mechanical behavior of the main objects of the system. The behavior of the crowd, for example, can be modeled using several rules of the behavior of each individual, and the development of the land use structure on the square can be modeled through a series of rules that describe the behavior of each decision maker. But with this approach for many systems, the number of major objects is too large for practical use. Continuous field models solve this problem by replacing individual objects with continuously changing estimates of such abstract properties as the density of people in the crowd, or the average speed and acceleration of water molecules that are considered as continuous liquids.

Aggregated models. Another approach is *to merge (aggregate)* individual objects into a single whole and model the system through the behavior of these aggregates. Thus, many simulations of human body systems occur at the aggregated level of census areas or paths, and many hydrological systems modeling occurs with large systems that aggregate regions into integral watersheds or sections of streams. Large systems ignore changes (including those of behavior) and processes within a holistic formation that are below spatial separation for reflection. Over time, increasing the capacity and capacity of computers have made the simulation on an individual level more practical, and today you can build models with the participation of millions and even billions of objects. The problem of determining the initial conditions remains relevant. However, it often results from real constraints in data collection, which often requires the use of expensive human resources. Such technology as remote sensing provides a partial solution that provides initial conditions on large areas to characterize in a good spatial separation, but optical remote sensing is limited in its ability to see through the clouds and distinguish areas based on properties in accordance with the research model.

Statistical models. Models can be static if the input and output are the same at the same time point, or dynamic, if the output represents a later time point than the input. A common element in all these models is the work of GIS in several stages, whether they will be used to create complex indicators from the input layers or to present time steps in the dynamic process. Static models often take the form of indicators by combining different materials to create a useful output. For example, the universal soil loss equation combines layers that represent information about slopes, soil quality in agricultural practice, as well as other properties for estimating the amount of soil that will be lost as a result of erosion per unit area per unit time.

Dynamic models, on the other hand, constitute a process that changes or transforms some aspects of the Earth's surface over time. Modern weather forecasts are based on dynamic atmospheric models. Dynamic river runoff models are used to predict floods, and dynamic models of human behavior are used to predict road congestion.

In *cellular automaton* spatial variations are represented as a raster of fixed resolution, each cell of which is assigned one of a finite set of certain states. For the operation of a cellular automaton, the tasks of the initial state of all cells and the rules of the transition of cells from one state to another are required. On each iteration, using the rules of transition and the formation of adjacent cells, a new state of each cell is determined. Usually, the rules of transition are the same for all cells and apply immediately to the entire lattice. Such models are often used to study urban expansion processes, and in this case, possible states that will be limited by two indicators: underdeveloped and developed. At each time step, the next state of each cell is determined by the number of rules based on the properties and on the state of the cell and its neighbors. For example, the rules for a model of a simple urban expansion can be as follows: if the cell is currently underdeveloped, it must be transformed into a developed cell with probability, which depends on the slope of the cell and proximity to the main transport links, zoning of the cell, the number of its closest neighbors, which are already developed; If the cell is currently under development, leave it unchanged.

Agent model is a series of interacting active objects that reflect objects and relationships in the real world. From the point of view of practical application, agent modeling can be defined as a modeling method that investigates the behavior of decentralized agents and how this behavior determines the behavior of the whole system as a whole. When the agent model is developed, the engineer introduces the parameters of the agents (it can be people, vehicles, cities, animals, etc.), defines their behavior, places them in some environment, establishes possible connections, and then launches the simulation. The individual behavior of each agent forms the global behavior of the simulated system. In the agent model, the dynamic behavior of the system is represented through rules that govern the actions of a number of autonomous agents. Such models can be considered as a generalization of a cellular automaton in which agents can move in space rather than being confined to a cell of a raster, but in other cases the location of agents may be irrelevant to the model. Agent-oriented modeling has found many interesting applications for geographic phenomena. For example, some efforts have been made to apply agent-based modeling in land use and land cover with a special emphasis on processes that lead to greater fragmentation of soil and vegetation cover. One of the factors that led to a recent increase in interest in agent models is the emergence of an object-oriented paradigm in the software developed. Well-known scientist Batty described the concept of modeling the actions of individuals in complex geographic landscapes by building a set of parallel, independent software modules, each of which represents the actions and decisions of one object in the system. The object-oriented language made it much easier to comprehend and build such simulation systems that are very different in the software architecture from the traditional serial approach to computing.

Conclusions. Today it is safe to say that modeling is a method of researching various phenomena and processes, and developing options for managerial decisions. The modeling is based on the substitution of real objects by their conditional samples, analogues. The method of modeling describes the structure of the object (static model), the process of its functioning and development (dynamic model). The model reproduces the properties, connections, trends of the studied systems and processes, which makes it possible to assess their condition, make a forecast, make a well-founded decision. Modeling forms are varied and depend on types of structural models and applications. Subject and sign modeling are highlighted. The subject one allows the creation of models that reproduce the spatial-temporal, functional, structural and other properties of the original (concrete-scientific models). The sign one is to represent the parameters of the object with the help of symbols, schemes, formulas, language suggestions (logic-mathematical models). Epistemological content of the modeling forms the basis for transferring the results obtained during the study of models to the original. To date, modeling of land management systems is one of the most important areas of the process of cognition of management activity and management relations and therefore serves as the most important management function along with regulatory and value regulation and information provision. Management modeling is referred to as the process of constructing and researching analogues of real phenomena, objects, processes, which reflect the most important, in terms of the purpose of management or research, properties and omitting secondary, insignificant ones. For example, the normative model of the control system provides an opportunity to present in the main features an improved management system that is interdependent with all its subsystems and elements, that is, modeling is considered not only as a means of analysis, but also as a basis for making specific decisions. One of the main strategic goals of *geoinformation modeling* is "to see the whole". Thanks to the geoinformation modeling, provided that a large number of reliable and accurate data is entered into the system, the user can identify deep system connections and trends that are not available through traditional methods of cognition. So, for example, the digital model of the terrain, developed on the basis of GIS-modeling, serves as a solid foundation for making decisions on the future state of the territory. The strategic goal of GIS modeling is to "manage the location." Geoinformation modeling in this case can provide a number of important analytical capabilities: analysis of the location of objects; construction of models of density of phenomena; search for objects within a particular area; analysis of the nearest neighborhood; simulation of changes; definition of spatial attributes of objects; division of objects by categories; search and definition of patterns of distribution of spatial and attribute data; three-dimensional visualization of end results.

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