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An object-oriented information model for territorial system management

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Abstract This article examines an object-oriented geospatial information model for territorial system management, its benefits compared to current automated territorial management systems, and special aspects of its development and implementation in multi-level geoinformation systems. The presented study reflects the major functions of geoinformation materials used in spatial planning, particularly in Earth remote sensing. A territorial information management model is developed from the perspective of the object-oriented geoinformation approach. The study identifies the major functions of the proposed management system and demonstrates what kinds of problems can be solved using this system, develops a spatial algorithmic model for managerial decision-making and a methodology for analyzing local territorial system characteristics; and introduces basic information arrays that can be used to solve practical territorial management problems at various levels.

Keywords Object-oriented geoinformation approach · Territorial systems · Management · Space · Stable spatial disequilibrium

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Introduction

The current information age can be characterized by intensive implementation of complex information systems aimed at solving territorial management problems based on geospatial information (GSI). This implementation requires the revision of development principles and approaches and of the application of geospatial information (Asiama et al. 2017). Information support organization problems related to the condition and use of territorial systems for effectively managing natural resources are globally present. For market entities and interested entrepreneurs, market information on territorial resources is not available in the required quantities, owing primarily to the specificity of this information and the inaccessibility of official data sources.

The comprehensiveness, efficiency, and accuracy of solutions to the diverse array of territorial management problems make it difficult to solve the problem of providing and implementing GSI using old methods.

In this regard, the timely comprehensive integration of diverse and relevant GSI through a net-centric approach and an object-oriented presentation of geospatial information become increasingly urgent and prioritized. What we need is a breakthrough in this direction, as distributed GSI databanks, which support information systems that aid in territorial management decision-making through the efficient functioning of object-oriented GSI databases, serve as the core element of a net-centric approach to providing geospatial information (Luo et al. 2017).

There are currently several problems associated with developing object-oriented GSI databases that could serve as a foundation for smart information systems based on net-centric territorial management principles and implementing cognitive geoinformation systems. First is creating object-oriented geospatial information models of basic spatial objects and thematically oriented objects. The development principles of such models focus on implementation in automated management systems. The main purpose of an information model is to connect subject areas and applied problems that should be solved using this information, i.e., it should provide the most expedient interface between applied problems and information stored in databases and increase the efficiency of processing methods and tools in various automation systems (Potts et al. 2017).

With the help of geoinformation technologies and systems, a large volume of information regarding objects with spatial reference can be effectively organized and accessed (Prisyazhnyuk 2013). For informational support to those who deal with the market economy or make managerial decisions, creating and using an object-oriented geoinformation system for managing territorial and territorially distributed systems is necessary.

An object-oriented geoinformation model for territorial system management is a new way to present spatial data aimed at information support of applied problems and simulation processes in cognitive geoinformation systems. This is achieved through maximum accuracy of cartographic objects as models of corresponding real-world objects (Prisyazhnyuk et al. 2014).

Research objectives

Our research objectives included (1) assessing information requirements and sources of information for the geospatial data for creating a thematic object-oriented geoinformation model to manage territories; (2) considering methodical approaches for the creation of a net-centric approach to an object-oriented geoinformation model to manage territories; (3) conducting a systems analysis of the subject area; (4) defining goals and functions of an object-oriented geoinformation model to manage territories.

Materials and methods

In this study, general scientific methods of cognition were used, including analysis and synthesis, dialectical and abstract logical reasoning, and systems analysis of the development of territorial processes. Moreover, methods of program-targeted planning, structural analysis, and economic analysis, such as analogies, groupings, comparisons, generalizations, typology, and rating, were used.

Results

Factor conditions for the evolution of control mechanisms of complex systems, which certainly include territorial systems, are included in numerous global processes. These processes include the development of global sales markets, improvement of the management of various types of systems, and development of the capabilities of information systems (Kaganovich 2014). Proceeding from this, the concept of "geoinformation management" has appeared.

In our opinion, geoinformation management is a management process involving spatial information (Prisyazhnyuk 2013). The goal of geoinformation management is to develop the most effective level-based variant of information support for the management process. The principal elements of geoinformation management are forecast function; planning function; organizational function; functions of control and motivation.

These functions must be effectively correlated with the spatial information that is involved in management activities and in the legal and regulatory framework.

Geoinformation management achieves the most effective and rational solution possible on the basis of the existing criteria, which includes spatial characteristics and a corresponding attribute description.

In conventional cartographic models, geospatial information focuses on the visual perception of cartographic material and not the internal composition of objects. This leads to information loss and the division of terrain features into separate parts, which makes software processing of GSI and applied problems in automated and geoinformation systems much more difficult. Geospatial data cannot be used to solve managerial decision-making support problems without preliminary preparation (e.g., stitching, correcting coordinates and attribute description values, and searching for missing object parts on maps of different scales or from different providers).

Creating multi-scale maps, which are produced by superimposing maps of different scales onto the same territory, causes significant difficulties under a "conventional" management model. Real-world objects consist of completely different unrelated map objects, which can cause numerous errors, make application software more complex, and increase the amount of information system resources needed, ultimately reducing territorial management efficiency.

Attempts to avoid these problems, such as stitching sheets into single regions or atlases or filling custom object attributes with references to other object parts, do not solve the main issue—the need to provide automated management systems with quality digital cartographic material intended for perception of the map by human senses and by computer vision and artificial intelligence systems (Fujita and Krugman 1995). This basically means transitioning toward comprehensive representation of terrain features close to natural conditions. Such a geospatial data model would be object-oriented rather than map-oriented (Fujita and Mori 1997).

The object-oriented geospatial approach to territorial system management undoubtedly provides more opportunities for efficient managerial decision-making and has the following benefits:

- Storage of all data of a single real-world territorial object in a single database (Amiti and Pissarides 2005);
- Automatic generation of maps according to specified properties (region, composition, scale, object, and attribute composition) (Behrens et al. 2007);
- Unambiguity, integrity, and consistency of geospatial data used in the calculation tasks of automated management systems in smart net-centric information systems that support territorial management decision-making;
- Spatial objects are updated one by one rather than according to nomenclature lists, making it possible to reduce GSI update costs by using data provided by relevant agencies (Dixit and Stiglitz 1977);
- Support at the level of a "topological relations" model between specified classes of spatial objects and fewer map errors due to the automatic control of topological relations between objects (Head and Ries 2001);
- Support of custom geospatial data models and arbitrary classification systems used in geoinformation systems of various purposes;
- During the transitional period, an object-oriented model allows database provisioning using a cartographic model and existing cartographic materials. This is made possible by the lack of cognitive geoinformation systems that work directly with the object-oriented model. However, with further development of cognitive object-oriented geoinformation systems, the object-oriented model should replace the "conventional" approach to spatial data (Hoare 1992).
- Thus, a smooth transition toward object-oriented bases containing knowledge about real-world objects with highly accurate coordinate referencing is achieved.

The basis of our proposed new spatial data model for information support of territorial management cognitive geoinformation systems is that a spatial object should be regarded as being part of a separate class based on only its essence, i.e., the property that distinguishes it from other objects and does not change throughout its entire "life cycle" (Kancs 2011). Examples of such essential spatial objects include motorways, watercourses, water bodies, tree vegetation, wetlands, settlements, and permanent structures (Krugman 1979).

Essential object locations should be described using coordinates or an address (or both). Territorial management objects may have several coordinate descriptions that differ terms of accuracy and level of detail, and they can all exist interrelatedly.

A spatial object may be an aggregation of other spatial objects without its own address or coordinates (for example, "street") (Murata 2003).

Essential classification of spatial objects and their unique identifications eliminate contradictions between different data providers and users, and allow shared use of object catalogs for metadata binding and information exchange in information and communication networks in protected modes.

A spatial object may also have different properties that do not affect its essence. These properties may appear and disappear or shift within the object, but they exist only with the object, and their locations can always be found in the object's coordinate description. The only property that describes an entire object is its "proper name" (Samuelson 1954).

The description of each property has its own location and distribution area both as linear and areal objects, meaning that properties get their own coordinate description in the object's general coordinate description without interfering with it. In turn, the property's coordinate description can be point like, linear, or areal.

Harmonization of such property descriptions revolves around the fact that, unlike the conventional territorial management model, property editing has no effect on the object's coordinate description. Each property is localized to a point, line, or area, and each property's description does not depend on descriptions of other properties, which may overlap and intersect.

Implementing hierarchical relations would make it possible to store only one item instead of duplicate property values in the management model. This automatically eliminates the risk of a discrepancy between object and caption attributes. At the same time, multiple captions displaying a property's values can be stored on maps of different scales using different symbols.

Some spatial objects, particularly long linear and large areal objects, can be identified as separate entities for more efficient territorial system management. Based on the essential definition of a spatial object and the principle of independent property description, we can separate an object into individual entities based on either its visual appearance or its proper name, which is usually the major property determining object separation.

The separated object's coordinate description should be continuous, if possible. Some examples of such objects are watercourses (rivers, streams, and canals), motorways and railways, power lines, and pipelines. Motorways are "correctly" separated by settlements where the street network "dilutes" the motorways passing through them, and not by settlements where motorways remain clearly discernible (Hermi et al. 2017; Ikechukwu et al. 2017). Similarly, railroads are separated by junctions. It is desirable to have a river with a proper name as a single object with a name value. Large areal objects like ground and vegetation are best separated by natural obstacles such as rivers or roads. Other unnatural types of object separation are to be avoided in an object-oriented model. The proposed object separation method proves useful in terms of object identification and spatial data infrastructure.

After implementing the above principles, it becomes obvious that the new object-oriented model is the most efficient existing geoinformation management model as of today.

The technology of spatial object representation in the proposed object-oriented model differs from that in conventional models for digital map representation in various geoinformation environments. Such differences include multiple options for an object's coordinate description or the total absence thereof, and a hierarchical relationship between the object, properties, and captions. Implementing such capabilities in existing geoinformation environments is challenging. In addition to this, there is a need for metadata monitoring and storage for each object attribute and coordinate description; therefore, it can be concluded that the only realistic environment for data monitoring in such a model is a relational management system for databases that require a storage space for spatial objects (Seenirajan et al. 2017). This storage would receive data from the geoinformation environment, which can then be used to monitor and generate the required sets of digital cartographic data upon request.

Implementing this new territorial system management approach requires a range of working models to be developed, namely:

1. A new catalog (classification) of spatial objects and rules of their separation. This catalog is being developed based on existing classifications with the following requirements: catalog items include only essential objects, objects are divided into groups along with their properties, all objects and attributes of the graphical representation of maps that can be obtained automatically using object properties are deleted, and special service attributes for describing metadata and hierarchical relations between objects and properties are added.
2. A model for converting existing areal maps for the new object catalog.
3. A model for stitching of objects into a single map per territorial unit.
4. Models for identifying spatial objects and recording metadata.

5. Models for data exchange, which in turn require an exchange format model.
6. A model of a smart (cognitive) object-oriented geoinformation system for services in a net-centric mode.
7. Models for integrating spatial objects into a secure unified geoinformation space with topological control between existing and added objects.

From the foregoing, we obtain the following axiom: The principal task of using the obtained results of systems analysis to make a spatial decision in object-oriented geoinformation management is to resolve a conflict that can block the activity of the entire system.

An analysis of favorable potential realization possibilities of administrative decisions is presented in Fig. 1.

The geoinformation management of territories reveals some characteristics that lead the environment and its objects to the inevitable presence of "development risks" (Ago et al. 2006; Martin and Rogers 1995), such as risks of development of territories and other organizationally complex spatial systems; risks to which any open systems are exposed; risks of a technogenic, social, economic, informational, and ecological character, and risks of a space–time character, forming zones and intervals of negative impact on objects and the environment as a whole.

Under such conditions of functioning of the mechanism of geoinformation management of territories, we have defined a "geoinformation management algorithm". The algorithm represents a "geoinformation management chain". This includes collection, generalization, and analysis of development risks; rationing of territorial development risks; assessment of the security level of the environment and risk objects; development and implementation of measures aimed at improving the territorial environment and individual objects' security levels; an assessment of the functioning of the mechanism of geoinformation management of territories; and risk analysis of the development of the next order.

In the mechanism of geoinformation management of territories, applying the "average risk index" is customary (Corpataux and Crevoisier 2007; Davis and Weinstein 2008), which in this aspect of the scientific problem characterizes the relative magnitude of the unrealized development potential (Dixit and Stiglitz 1977; Head and Ries 2001):

$$Rsum = \sum_{j=1}^{n} \frac{Qj \cdot kj}{n}, \quad (1)$$

where $Q_j = 1 - P \cdot (X_j \in D_j)$ is the probability of occurrence of risk on i event, X_i represents the events affecting the potential of the territory, D_i represents the limits of admissible values for the X_i parameters, K_i is the damage coefficient, and n is the number of parameters to be examined.

The average risk index ranges from zero to one. It accurately determines the level of potential losses and is a predicted value for the events that we forecast in the course of the development of the territories.

Conclusion

The results of the conducted research demonstrate that spatial information is the basis of the object-oriented geoinformation approach to the management of territories. With this type of management, space is regarded as a conceivable logical environment, a place for all other objects and constructions to be located. The process of acquiring any spatial information is possible only in conditions of institutional, economic, technical, ecological, and social analysis of the available potential for the development of a particular territory. The methods that are used to justify particular managerial decisions in the geoinformation approach to the management of territories must satisfy strict requirements.

Implementing the proposed object-oriented representation of geospatial information in the form of a new technology for forming a unified geoinformation space provides new competitive advantages. These advantages include high-quality description of management object properties, high-speed updates of spatial data, reduced spatial data storage size, high-speed provision to the user of updated geospatial information with the required level of detail, more efficient resource accounting in relation to territories and economic policy, a more efficient data security system, easy-to-use geoinformation systems, enhanced data access capabilities, a high level of unification in terms of integration with other national grade geoinformation systems, and creation of efficient knowledge bases containing information about the physical world.

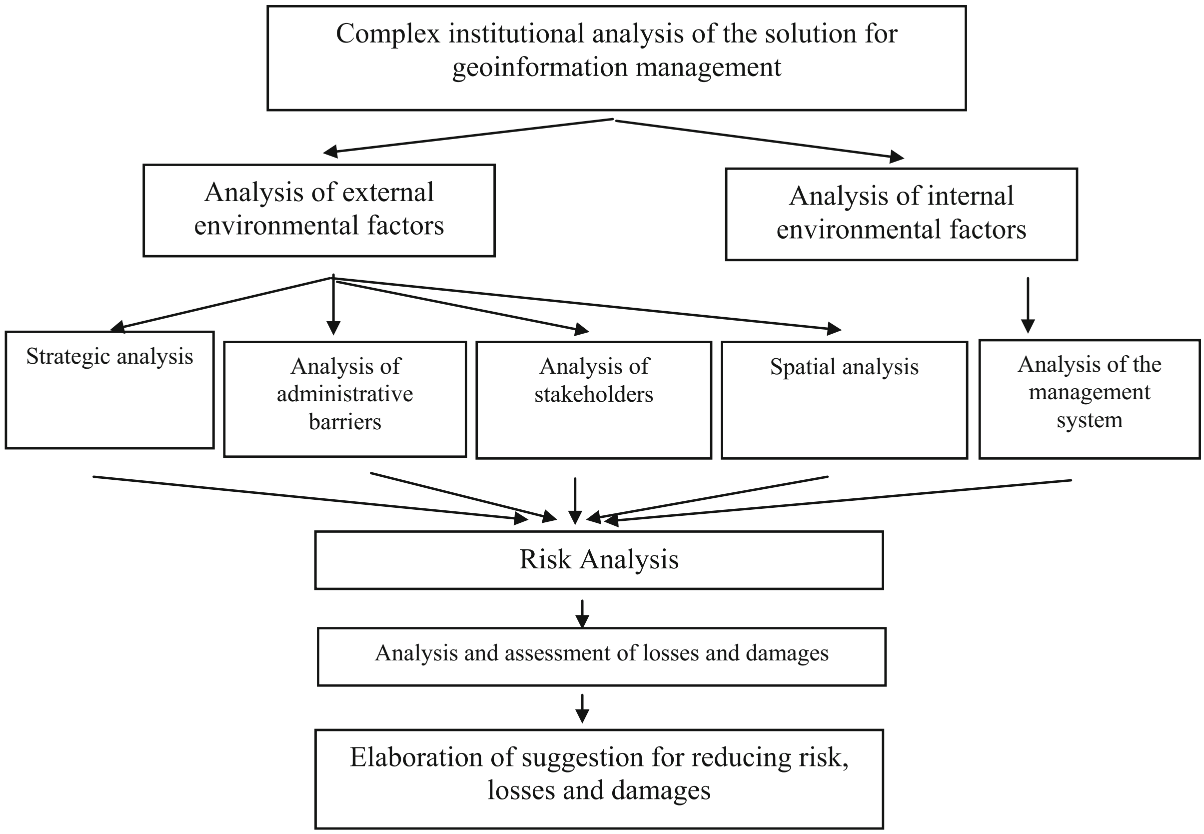

Fig. 1 Model of complex institutional analysis of managerial decisions

Compliance with ethical standards

Conflict of interest The authors declare no conflicts on interest.

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