

Method of intellectualization for geospatial processes control systems

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Abstract. Modern means of management intellectualization or dispatching of geospatial processes do not allow to take into account quickly and with sufficient degree of adequacy the changing properties of the natural environment that affect the managerial decisions made in dispatching by complexly distributed sets of geospatial processes. At the same time dispatching is the final manifestation of a multifaceted process of managing geospatial processes. Traditionally, the task of managing objects implementing geospatial processes is solved in isolation from the current state of the natural environment of their flow, without taking into account the variability of its radio technical, physical and other characteristics. Only issues of changes in navigational and meteorological conditions, as well as issues related to ensuring spatial security, are subject into account. Considerable interest in modern conditions presents a more complex variant of the problem of intelligent dispatching of spatial processes: when the variability of the environment determines unique conditions for dispatching at each point of the coordinated geographical space. Especially such a statement of the problem is relevant in the context of the introduction of modern adaptive means of monitoring and sensing the natural environment, as subsystems for monitoring the corresponding control systems for spatial processes. The novelty of this formulation and the method of solving this version of the problem lies in the merging of data from the domain of representation of spatial processes with knowledge, data corresponding to typical models of digital data sets, integration of software mechanisms for working with information on geospatial processes and programs for working with cartographic data sets. The development of a well-founded formulation and a method for solving this variant of the problem is the essence of this article.

1. Introduction

The article reveals a method for solving the problem of intellectual decision support using digital cartographic data sets when managing (dispatching) processes of movement of dynamic objects in geographic space. The term "dispatching spatial processes in geographical space" means a constant and continuous impact on controlled spatial processes in order to ensure the safety of their mutual flow. At the same time, the "spatial process" is a process that develops in geographical space over time (ship movement, aircraft flight, etc.).



The method is based on an approach to the organization of intellectual decision support based on the integration of methods of artificial intelligence and GIS technologies for processing digital cartographic data sets. The implementation of this method is assumed as a sequence of solving a number of particular problems:

- specification of the conceptual model of the application of digital cartographic data sets for intellectual support of decision-making in the dispatching of geospatial processes;
- specification of the requirements system, logical structure and software architecture of intelligent decision support systems for geospatial processes dispatching using data from digital cartographic sets;
- definition of the ontological model of the geospatial processes dispatching domain as a model for representing geospatial processes using digital cartographic data sets;
- implementation of a set of techniques to support the dispatching of spatial processes.

A meaningful description of the essence of the transformations performed at each stage of the method - in solving each particular problem, allows one to disclose the method as a whole.

2. Modern state of research on intellectual support of adoption of dispatch solutions

The development of effective methods of intellectual support for decision-making in the management and dispatching of spatial processes using digital cartographic data sets is a promising and demanded scientific and technological direction in the work of the world's leading centers of the software industry and university science. First of all, this subject is the subject of research of specialists in the management of transport flows and spatial logistics. Thus, in the works of domestic scientists [1,2] and in international publications [3,4], general principles and basic methods for intellectual support for the adoption of dispatch decisions based on the use of heterogeneous data from digital cartographic sets were developed and proposed. Approaches to the solution of the task of dispatching multiple and complex sets of geospatial processes in conditions where processing of large volumes of specific, relevant information in real time is required to make operative and justified decisions is also considered in sufficient detail in scientific publications [5-9]. However, at the present stage, a more complex option seems more promising: when decision support in the dispatching of geospatial processes requires the real-time variability of the environment, some current conditions for dispatching a mobile object at every point of geographic space.

Recently, interest in the creation of the corresponding scientific, methodological and information tools has increased significantly, as evidenced by the following facts:

- Active development in the Internet of network services and services to provide operational information on changes in the natural environment (states of layers of the atmosphere, water layers of the world's oceans, etc.).
- Obvious growth in the framework of leading scientific conferences and seminars on geoinformation topics of papers and reports devoted to the development of approaches to the use of geospatial data in solving various tasks of managing objects in geographic space. Such tasks include: dispatching geospatial processes in a dynamically changing environment; optimization of search efforts in conditions of spatial variability of the environment and etc.
- Steady growth in the costs of transport and logistics companies, state allocations for the development of intelligent dispatch infrastructure for various modes of transport, global positioning systems in combination with specialized management and logistics complexes.
- The emergence of advanced development of specialized GIS-services for access to digital geospatial data on the environment.

The analysis of the literature on the topic of intellectual support for decision-making in the dispatching of geospatial processes and the use of digital cartographic data sets in managing complex spatially distributed mobile systems that take into account modern ideas about the influence of the environment on the validity and correctness of the decisions made shows that the most effective ways of integrating the above scientific and technological directions are as following:

- active use of methods of harmonization, integration and merging of subject and geospatial information. Systematization of cartographic data sets;
- implementation of software solutions on the basis of domain ontologies, developed using data structures based on metadata and metametadata;
- intellectualization of models and decision support procedures in applied tasks of dispatching geospatial processes implemented in geoinformation systems.

Each of these methods has its own application technologies for implementing the corresponding functionality. The basis for the method proposed in this article, as an appropriate scientific, methodological and technological solution, is to lay down mechanisms that generalize the possibilities of the methods described above.

This will make it possible to obtain practical software and information technologies for the use of digital cartographic data sets in the management of complex distributed systems of mobile objects, taking into account modern ideas about the influence of the environment on the possibilities for justifying operational and correct dispatch solutions, etc. Especially relevant are the scientific and methodological solutions being developed and are for specialists in the field of practical navigation of transport objects, as well as for specialists in technical monitoring systems, radar, hydroacoustics, etc.

This thesis is actual due to the pronounced binding of dispatched (detected, detected) objects to certain geographic coordinates; the obvious need for specialized tools for the operational visualization of the results of dispatch or detection. There are also a number of other studies that are exploratory with the subject of this study, for example [10–11].

However, the direct competitors who solve the task of recording the characteristics of the natural environment with intellectual support for the adoption of dispatch solutions were not found by the authors. The analysis of the field of development of intelligent decision support systems, as well as specialized GIS applications for working with digital cartographic data sets, makes it possible to assess the theoretical level of the proposed method as comparable to the world one, and in some cases surpassing it.

3. Stages of application of cartographic data kits for intellectual support of administration of controlled decisions

The basis of intellectual decision support in the dispatching of geospatial processes with the use of digital cartographic data sets is the combination of models and methods for merging data from the domain of representation of spatial processes with data corresponding to typical models of digital data sets, integration of software mechanisms for working with information on geospatial processes and work programs with cartographic data sets.

Modeling of geospatial processes and intelligent support for solutions for their dispatching is carried out using technologies for working with complex structured spatial data based on ontologies of subject areas. In this case, the basis for developing recommendations for control actions is the scenario of the regular flow of the spatial process. It is the degree of deviation of this or that geospatial process from the regular scenario of its flow that determines the necessity and scope of the dispatching influence. The purpose of such an impact is to reduce this deviation to an acceptable one. The individual means proposed within the framework of the method are aimed at developing rational sequences of actions for formulating and evaluating the parameters of such dispatching impacts.

The components of the process of supporting the adoption of dispatch solutions are the following:

- application of digital cartographic data sets for managing distributed sources of information about the course of geospatial processes;
- the use of geospatial data in the process of analysing trajectories and predicting the locations of objects that implement spatial processes;
- applying geospatial data as the basis of the model of the environment;
- application of geospatial data to assess the situation and develop control actions.

4. Intellectualization of simulation of geospatial processes

Modeling of geospatial processes, carried out in dispatching systems, can be considered as a certain homomorphic transformation. any homomorphism generates a model; each model is determined by a certain homomorphism, and the choice of the corresponding homomorphism depends on which properties of the initial process are considered essential for modeling. With this approach, the main principle of system modeling is the principle of multimodality. Its implementation with respect to the problem of identifying abnormal situations in the course of several geospatial processes is expressed in the construction and use in practice of a hierarchical system of models of expert knowledge. So, we can assume that on a set of models of expertise there is a model $M = \{M_i, i = \overline{1, n}\}$ of the binary relation $r_m = \langle M, R_m \rangle, R_m \subseteq M \times M$. This relation is further referred to as the modeling relationship, determined on the basis of the introduction of the concept of modeling level: the model $M_i (i = \overline{1, n})$ is a model of expertise of the i - level of modeling (formalization) and model of the $(i - j)$ - level towards to the model $M_j (j = \overline{1, i})$. For example, the model M_3 is a model of expert knowledge of the 3-rd level and a model of the 2-nd level in relation to M_1 . Thus, the fact that some ordered pair of models $\langle M_i, M_j \rangle (i, j = \overline{1, n}, i \geq j)$ is related to the modeling relationship (which is written as $M_i r_M M_j$ or as $\langle M_i, M_j \rangle \in R_M$) meaning: model of expertise M_i is a model (metamodel) of the $(i - j)$ - level towards to the model (object model) M_j .

It is natural to assume that the introduced relationship has the following properties: reflexivity; antisymmetry; transitivity; completeness.

The number of links in the chain of models should be determined, on the one hand, by the specific nature of the geospatial processes being simulated and the nature of the tasks to be controlled by them, on the other hand, by the characteristics of the expert and the knowledge engineer in the process of multi-stage multi-level formalization of expert knowledge. The following requirements are imposed on the system of expert knowledge models:

- transitions between modeling levels should not cause difficulties for the expert and the knowledge engineer in the course of their joint activity in creating the knowledge base of the intelligent subsystem supporting the controller's decisions;
- in the transition from the model of expert knowledge of one (higher) to the model of another (lower) level of formalization, loss and / or distortion of information is unacceptable.

Taking into account the above requirements, as well as on the basis of the specific features of the spatial process dispatching area, it is possible to propose a number of levels of modeling (formalization) of expert knowledge that can be conditionally called conceptual, structural-semantic, structural-formal, formal and programmatic.

The features of representation of expert knowledge at each of the modeling levels are reduced to the following:

- the conceptual model of expert knowledge, being their "primary" model, corresponds to the verbal description by the expert of the set of concepts allocated in the subject area of the dispatching of spatial processes and their interrelations (ontology of the subject area). They should also include various kinds of provisions for title documents, manuals, manuals, instructions, etc., adopted to describe the standard of the spatial situation;
- the construction of the structural-semantic model of expert knowledge is related to the structuring of a selected set of concepts of the subject domain by forming the structure of the conceptual system in explicit form;
- the structural-formal model of expert knowledge contains two components: structural and formal. The first of them is identical to the corresponding component of the structural-content model, and the second, the formal component, is the result of formalizing the content component of the structural-content model by means of some formal language;
- the formal model of expert knowledge, unlike the structural-formal model, is characterized by the absence of a structural component and the presence of formal-linguistic structures that help formalize expert knowledge;

- a program model of expertise is formed as a result of the presentation of a formal model with the help of appropriate software and tools for presenting expertise.

The complex of developed models makes up the knowledge base of the expert system for intellectual support of solutions for dispatching spatial processes, which in turn is a means of forming separate reference spatial situations and scenarios for the correct development of dispatched spatial processes.

5. Assessment of the efficiency and effectiveness of the proposed method

Efficiency evaluation was carried out in the framework of the experiment, which was carried out using simulation tools in relation to the characteristics of a typical dispatching system. The purpose of the experiment was to establish the fact of a statistically significant increase in the effectiveness (i.e. its components) of the dispatching system by implementing methods of intellectual support for decision-making in its application software. At the same time, the performance components are considered as some quality indicators for dispatching, and the fact of the increase in the effectiveness of these components is seen as evidence of its improvement. As contrasting alternatives in the experiment, the following are considered: (i) using traditional dispatching and support solutions of the dispatcher on the basis of mathematical and algorithmic models of problems of identifying and resolving collisions in the development of spatial processes; (ii) using of intelligent support for the adoption of dispatch solutions, implemented on the basis of digital cartographic data sets and software technology of expert systems for solving the same range of problems.

In the process of mathematical-statistical modeling and comparative analysis of alternative variants, three series of assessments (twelve acts each) of performance indicators of prototypes were carried out. It was assumed that alternative prototypes were used for the automated detection and resolution of collisions in the air transport movement, which were modeled and analyzed in the MathCAD 2000 Professional environment, by combining data on civil aviation aircraft from the site [12] and from the database of small aircraft in the equivalent status. This combination allowed to simulate the appearance of collisions that need to be identified and prevented using air traffic control systems. As an experimental area, air space was considered over the Gulf of Finland and nearby airports. This allowed us to use uniform, typical and closest to reliable versions of the input information for the dispatching of geospatial processes with each evaluation act.

6. Conclusions

The effectiveness of the dispatching of spatial processes in the corresponding geographic area is determined by the quality of information processing at individual stages of the functioning of the multi-level dispatching support system. The existing directions of development of intellectual decision support tools, complexes of work with digital cartographic data of different thematic orientation, models of the surrounding geographic environment make it possible to apply geospatial data at all levels of dispatching and management of objects implementing spatial processes. In turn, this fact provides a basis for increasing the degree of reliability of the relevant information models of the situation and making more informed dispatch decisions. However, working with geospatial information requires not only the use of complex logic-mathematical and software-calculation models, but also an original approach to the intellectualization of modeling the processing of relevant information. Realization of the specified models and approaches, intellectualization of support of acceptance of dispatching decisions in the near future will provide essentially new level of automation of functioning of systems of dispatching of geospatial processes.

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