Information support for decision-making in emergency situations

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Abstract. In this article, the technology of information support for decision-making in the event of natural and technogenic emergencies is considered. Its implementation was carried out using the created information system (IS) for predicting the consequences of emergency situations, which is based on a single information space of the territory of the subject of the Russian Federation. The paper proposes an approach to creating an IS based on a distributed, peer-to-peer architecture when information resources (in relation to the considered IS) are not only presented as data, but also as various applications of basic ISs. A geographical information system is used as a basic one for solving problems of forecasting development and consequences of emergency situations. The decision support subsystem meets the following requirements: provides forecasts of occurrence and development of emergency situations in the form of predictive bulletins for review and approval of the management; provides paperwork for submission to rapid response services. Calculation of consequences of emergency situations is based on the following methods: assessment of consequences of accidents at explosive and fire-hazardous objects; forecasting and assessment of medical consequences of accidents at explosive and fire-hazardous objects; predicting the extent of contamination with highly toxic substances in accidents (destruction) at hazardous chemical facilities and transport; predicting possible accidents, catastrophes, and natural disasters; assessing damage from man-made, natural and terrorist emergencies, as well as classifying and recording them.

1. Introduction

Physical and geographical, climatic, ethnic and demographic features of the Russian Federation, combined with the number and location of man-made sources of danger, make the task of protecting the population and territories from natural and man-made emergencies a priority.

The need for diverse, timely, accurate and adequate information about the state of a natural and industrial system (NIS) for making timely managerial decisions related to prevention of possible consequences of various emergencies makes it necessary to use information systems (IS) that track all possible states of a NIS, various influences on it, and models NIS behavior as a complex system. At the same time, the more diverse are data collection systems, the higher is reliability of received materials. Taking into account the size of the territory of the Russian Federation and its administrative structure, the work in the field of monitoring and forecasting of emergency situations should be based on the principle of territorial distribution.
A number of publications are currently devoted to forecasting natural, technogenic, technogenic-natural, technogenic-natural emergencies. The article [1] considers modern spatial and temporal spread patterns of emergency situations in the subjects of the Siberian Federal district. It analyzes economic, social and environmental situation in these areas and provides information about spatial structure of natural and technogenic emergencies that occurred there. The study presents a novel method for analyzing the subjects of the Siberian Federal district and includes information about transport, protection from natural disasters, environmental stress, etc. The article provides information about natural and man-made emergencies from 2000 to 2013, which is grouped by social situations in each region. The authors of the work [2] pay special attention to studying emergency situations that arise on the basis of natural and anthropogenic factors in various regions of Kazakhstan, as well as to training of specialists who know regional features and specifics of mental values of its inhabitants. Professional competence, tolerance, spiritual and physical fitness, organizational skills and responsibility - all these qualities are essential for specialists who work in emergency situations and whose activities are aimed at protecting the environment. The orientation of society towards cost-effective use of natural resources in accordance with the requirements of environmental protection, formation of public consciousness based on respect to nature, as well as formation of ethically interdependent interaction with it requires high professionalism from people who are directly involved in prevention and elimination of risks arising from natural and man-made emergencies.

Article [3] presents a combined method for predicting the occurrence of natural disasters. Unlike other methods, it allows for comprehensive forecasting of emergency situations, both in general and by type, taking into account the trends of periodic changes in the process. As the generalized parameter of the process, the authors considered a number of accidents over a certain period of time. Taking into account the influence of all destabilizing factors, the authors present the process as an additive mixture of systematic, periodic and random components. The systematic component is a polynomial of some degree. The authors detected and evaluated the periodic component based on the statistical criterion that obeys Chi-square distribution. To predict the random component, the method of group consideration of arguments was applied. Forecasting of emergency situations by type was carried out using the probabilistic and statistical forecasting method. The need to develop a combined forecasting method arises from the fact that existing methods of forecasting emergency situations are mainly focused on forecasting certain types of disasters and thus do not solve the problem of complex forecasting of emergency situations. It should also be noted that the occurrence of natural disasters is characterized by the presence of periodic components. Taking such components into account in predicting emergency situations makes the analysis of occurrence and development of emergency situations more profound. In the course of experimental studies, it was found that the use of combined method allows predicting emergency situations for at least a year ahead with the relative forecast error of no more than three percent. The combined method unites the method of regression analysis, the method of testing statistical hypotheses, and the method of group consideration of arguments. This proves usefulness and expediency of the method and allows compensating for the shortcomings of some methods with the others and thus increasing the accuracy of the forecast.

Creating a managerial decision-support system based on emergency forecasting that combines solutions to all types of natural and man-made emergencies and allows for rapid response to emergencies in the current conditions is a very complicated task [4 - 7]. At the same time, the use of various monitoring systems makes it necessary to develop a conceptual approach to formation of a single information space (SIS) of a NIS.

2. Single information space

We introduce the concept of a SIS of a NIS on the scale of the subject of the Russian Federation. A SIS is a set of information tools and resources integrated into a single system, namely:

1. actual information resources (arrays of documents, databases and data banks, all types of archives, etc., containing recorded information);
2. network and special software;
3. telecommunication network (geographically distributed corporate computer networks, telecommunication networks and systems for special purposes and general use, networks and data transmission channels, means of switching and managing information flows).

A SIS is based on a digital spatial model of NIS’s territory on the scale of the subject of the Russian Federation including all objects that form a single technical, economic and environmental structure of the area under consideration interacting with each other in an orderly manner in the processes of information exchange, consumption of material and energy resources.

When automating NIS modeling, the following tasks must be solved: select an adequate graphical model; create an attributive description of model’s objects; select or develop tools for displaying, storing and editing graphical and attributive data; link graphic objects and their attributive descriptions into a single integrated model, that is, create a “technological” model of a NIS; create tools for analyzing and processing of data presented in the model [8]; provide input of visual data into the system, interpretation and output of data processing results.

In order to form a SIS, it is necessary to create an automated IS, which helps a specialist to make optimal managerial decisions. An IS is a technological system that represents a set of technical, software and other tools that are combined structurally and functionally to provide one or more types of information processes and information services. The main components of the system can include basic and applied software, complexes, networks and systems that can be combined into one structure to perform one or more functions: collection, storage (accumulation), processing (production), search, dissemination (distribution, transmission), reception (consumption) of information and provision of information services.

In this paper, we propose an approach to creating an IS based on a distributed, peer-to-peer architecture when information resources (in relation to the considered IS) are not only represented as data, but also as various applications of basic ISs. Then, in each of them, some of data processing methods are implemented in the form of applications available from other IS. For example, when two ISs interact, the first uses the services provided by the second, and as a result it receives processed data that can be further processed by the components of the first system.

Taking into account the emerging global trends in the field of creating applied ISs, it is proposed to use the following modern information technologies when implementing the proposed approach: GIS technologies; Internet technologies; the ideology of information storage and "client-server" architecture; SQL-oriented tool systems (ORACLE, INFORMIX, etc.); CASE-technologies for designing ISs and databases.

The created IS should be implemented at two levels: at the first level - in the form of automated workplaces (AWP) using a single computer; at the second level - in the form of local computer networks that connect from two to several dozen computers (workstations) and peripheral devices within the NIS in a single unit for the purpose of sharing access to common resources and mutual exchange of information.

A geographical information system (GIS) should be identified as the basic information systems used for solving problems on the NIS scale [9 - 11]. This system provides storage and graphical representation of objects that have a certain position on the ground. For each object, the database stores its coordinates, dimensions, display rules, name, and code for linking to other databases that contain additional information about the objects. It is known that currently 80% of decisions are related to spatial reference to the area. An instrumental GIS includes tools for creating and editing new thematic layers, individual objects, selective visualization of layers, measurements and calculations, and programming tools for new analytical tasks. It also provides solutions to the problems of input and digital encoding of images directly from primary source of visual data, problems of vectorization of raster images combining layers of a spatial model in a single coordinate system, etc.

Most modern GIS have three-dimensional modeling tools. They can be used to identify and examine all the main characteristics and features of interaction and relationships between NIS components, both in spatial and temporal aspects.
3. Spatial model of a territory

When creating a digital spatial model of the NIS’s territory, depending on the aims, it is advisable to use the coordinate system adopted for this territory, for example, Pulkovo 1942. Raster and vector models can be used to describe various objects that are parts of the NIS. Moreover, a raster model is used as a primary data source. The scale of the model (1:25000, 1:10000, etc.) is selected depending on the scale of possible consequences of various emergencies and accuracy of forecasts.

Depending on the complexity of the object’s shape, a certain graphic primitive can be used to describe it. Point-type objects are those located at only one point in space. Linear objects are represented as one-dimensional in the coordinate space. Projections of polygonal (areal) objects on the x0y coordinate plane represent areas approximated by polygons. For example, various buildings and structures are defined in the form of parallelepipeds or cylinders. A model called triangulated irregular network (TIN) is used to represent surfaces.

In addition to data about a geometric shape of an object, each of them is provided with a variety of attributive information stored either as separate tables within a single database, or as independent data sets linked by a set of pointers and combined in a GEODATA Bank.

When developing a managerial decision support system for emergency forecasting in the Tambov region, ArcGIS software by ESRI Corporation is used as the basic software as this system meets the requirements listed above to the fullest extent.

4. Principles of making emergency forecasts

When developing a methodology for forecasting emergency situations, it is necessary to create a system of principles for making emergency forecasts, logically organized into a single technological structure.

A set of methodological principles for forecasting emergency situations should have sufficient unification and universality for systematic solution of forecasting problems at all its stages, starting from an early forecast and ending with the forecast of consequences arising from emergency situations. Thus, the methodology for predicting emergencies of all types should be based on the following three principles:

1. it is mandatory to take into account the level of actual and predicted solar activity and its impact on initiation of natural sources of emergencies, performance of operators at all levels, and reliability of complex electronic systems, energy systems, and communications;
2. it is necessary to take into account the level of synergy of processes and phenomena that form secondary sources of emergencies;
3. the forecast must be presented in a probabilistic form.

5. Structure and functions of an information system

There are generally four types of emergency situations: natural, technogenic (man-made), natural-technogenic, and technogenic-natural.

Taking into account that natural-technogenic and technogenic-natural emergencies are categories of mixed genesis and at the same time have identical sources, it seems appropriate to combine them into a single group of natural-technogenic emergencies.

An equally inherent factor for all three classes of emergencies is that the forecasting task is divided into two sub-tasks that differ in their goals. It is obvious that first of all it is necessary to solve the problem of early forecasting of disasters. In case of emergency situations, it is necessary to solve the problem of forecasting the development and consequences of emergency situations. Thus, emergency forecasts should be divided into two classes:

1. advance emergency forecasts;
2. forecasts of emergency situations development and their consequences.

Therefore, it is advisable to divide the entire IS’s structure into three subsystems, each of which performs its own functions.

The subsystem of emergency situations forecasting should meet the following functional requirements:
1. provide predictive analysis of monitoring and forecast information about the sources of emergencies;
2. develop forecasts of occurrence and development of emergency situations;
3. ensure creation and maintenance of a database on forecasts of occurrence and development of emergency situations and data on their justifiability;
4. ensure processing of monitoring and predictive data aimed at identifying new and more effective predictive relationships between the state of emergency sources, causes of occurrence, conditions for development of emergency situations and their parameters.

The subsystem for predicting the consequences of technogenic emergencies must meet the following functional requirements:
1. provide predictive analysis of data on assessment of consequences of man-made emergencies and forecasts of man-made emergencies;
2. develop forecasts of the consequences of man-made emergencies;
3. ensure creation and maintenance of a database of forecasts of the consequences of technogenic emergencies and the degree of their justifiability;
4. provide processing of monitoring and predictive data aimed at identifying new and more effective predictive relationships between the parameters, conditions of occurrence, development and the course of man-made emergencies and their consequences.

The decision support subsystem must meet the following functional requirements:
1. submit forecasts of occurrence and development of emergencies in predictive bulletins for review and approval of the management;
2. ensure preparation of regulatory paperwork for the objects;
3. ensure preparation of paperwork for submission to rapid response services.

The calculation of consequences of emergencies is based on the following methods:
1. assessment of consequences of accidents at explosive and fire-hazardous facilities;
2. forecasting and assessment of medical consequences of accidents at explosive and fire-hazardous facilities;
3. forecasting the scale of contamination with highly toxic substances in accidents (destruction) at chemically hazardous facilities and transport;
4. forecasting possible accidents, catastrophes, and natural disasters;
5. assessment of damage caused by man-made, natural and terrorist emergencies, as well as classification and recording of emergencies.

6. Results of forecasting and discussion
Based on the proposed approach to building a managerial decision support system based on predicting emergency situations on the scale of the subject of the Russian Federation, a spatial model of several districts of Tambov is currently created, a fragment of which is shown (in Figure 1). To do this, the following tasks were set and solved:
1. forecasting the consequences of explosions of containers with explosive and fire-hazardous substances at fire and explosive objects (the results of the forecast are shown in Figure 2);
2. forecasting the consequences of leaks of chemical hazardous substances;
3. forecasting the effects of hurricanes (see Figure 3).

The results of solving these tasks will significantly contribute to normal functioning of the NIS.
Figure 1. A fragment of the spatial model of the north-eastern industrial district of Tambov.

Figure 2. Visualization of the blast wave zone and objects caught in the shock wave front.

7. Conclusion
The authors propose a technology for information support of managerial decision-making in events of natural and technogenic emergencies. For its implementation, an information system for predicting the consequences of emergency situations was developed, which is based on a single information space of the territory on the scale of the subject of the Russian Federation.
A geographical information system is used as the basic information system for solving problems of forecasting the development and consequences of emergency situations. The decision support subsystem meets the following requirements: provide forecasts of occurrence and development of emergency situations in predictive bulletins to be reviewed and approved by the management; provide paperwork for submission to rapid response services. The calculation of consequences of emergencies is based on the following methods: assessment of consequences of accidents at explosive and fire-hazardous facilities; forecasting and assessment of medical consequences of accidents at explosive and fire-hazardous facilities; forecasting the extent of contamination with highly toxic substances in accidents (destruction) at hazardous chemical facilities and transport; forecasting possible accidents, catastrophes, natural disasters; assessing damage from man-made, natural and terrorist emergencies, as well as classification and recording of emergencies.

The system was tested on the example of data provided by Tambov regional state institution "Fire and rescue center" (Russia).

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