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Modeling of Environmental Safety of Industrially Developed Regions of Russia

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***Abstract* – The paper presents the study on modeling of objects and processes to forecast environmental safety in industrially developed regions of Russia. It is shown that the sources of pollution of the regional environment form a complex technogenic system triggering the development of qualitatively new negative processes violating comfortable living conditions of the local population. The complexity and scientific uncertainty of environmental impacts caused the development of modern methods of analysis of environmental safety in the region. The purpose of experimental and theoretical study was to develop a rational complex of modeling procedures ensuring reliable forecast as a basis of efficient solution to manage regional environmental condition. The above purpose was achieved via joint use of such mathematical methods as the integrated system analysis, synthesis of alternatives, algorithmization of processes and generalization of experimental data.**

Keywords – environmental safety; modeling; region; natural and technical system; forecasting.

I. INTRODUCTION

Environmental safety has become ever urgent for Russia due to negative environmental impacts of production activity. The environmental situation in industrial regions is characterized by high level of pollution of the surrounding environment (SE). At the same time the actual concentration of such harmful substances as compounds of chlorine, nitrogen and sulfur in certain territories several times exceeds the admissible concentration limit.

The unsatisfactory condition of SE caused the need for scientific study of waste-free technologies to decrease the anthropogenic impact on the environment. This results in the development of various techniques to estimate and predict the condition of environmental safety in the territory of industrial agglomerations [1-9].

One of effective tools of SE analysis is modeling based on computer technologies. At the same time, the analytical review of publications on the matter shows lack of system approach to the solution of environmental modelling problems. The scientists focus on private models characterizing the pollution of environmental objects under the influence of various harmful substances. Thus, Mokhov A.V., Norvatov Yu.A., Oparin V.N. and Savelyev D.I. only consider the impact of production on hydrosphere [1-3]. Other scientists, including Voznesensky A.S., Bilgin N., Gattinoni P., estimate in details the geomechanical phenomena in the rock massif of industrial complexes [4-6]. Scientific articles of Belodedov A.A., V.I., Maslennikov S.A. and Stradanchenko S.G. are devoted to the assessment of the impact of ore “tailings dams” and mountain production technologies on the environment [7-9]. The results of the above studies are important to understand the scales of negative impact of production on environmental safety of a particular region. At the same time fragmentary estimates diminish the general understanding of the condition of regional environmental safety.

Due to the stated results of the analysis the authors believe that the development of theoretical and practical issues of environmental safety modeling in terms of the integrated approach is a relevant scientific task. The purpose of research work is to justify a complex of modeling procedures ensuring assessment and forecasting of environmental parameters of the region. The development of a complex of models covering a full range of real situations shall be based on detailed analysis of negative technogenic factors and their relations in compliance with the methodology described in [10].

II. Methods and materials

The objects of regional environment defining environmental safety represent a complex multilevel system characterized by a variety of interrelations. The specified situation justifies the use of the corresponding strategy and methods ensuring correct solution of environmental modeling. In the context of the study it shall be noted that modelling is a significant investigation phase of regional safety. The results of subsequent analysis of real objects strongly depend on the quality of the developed models. In this regard the authors consider that the integrated system analysis (ISA) ensuring realization of radical properties of a complex system shall be used as the main analytical tool in implementing all modeling procedures.

The ISA of environmental safety condition makes it possible to develop the modeling strategy of regional objects and their interaction. At the same time the following tasks are solved:

- detection of object size;

- development of structural characteristics;

- joint assessment of the first two procedures.

The modelling of a system of environmental safety shall consider scientific principles and approaches tested through long-term practice of modeling. The experts consider the following principles as fundamental provisions of modeling:

- adequacy;

- compliance of a designed to an objective;

- simplification of a model on obligatory compliance with radical properties of a system;

- compromise between complexity of a model and accuracy of modeling results;

- balance of errors of dimensional types;

- block structure of a formulated model;

- multivariance of model components.

According to the authors, the block principle of modeling is identification of separate blocks of objects and formation of the corresponding models with minimum relations. The modeling of complex systems is always connected with the development of a tuple of hierarchical models, which have different level of displayed operations. At the same time the necessary procedure is identify subsystems and operating objects as the levels of a system. Three main analytical procedures are used within the system approach to modeling:

- analysis and assessment of basic data on the system and the external environment;

- some experiments on a limited basis directly on a real object;

- direct analysis of system functioning.

When using modeling the researchers shall choose methods of model creation. In this context it is necessary to ensure correct mathematical description of the model serving the reflection of the entity object taking into account its features. The main task of model creation is to search for an optimal solution, which is reached by a compromise between complexity of the designed model and its adequacy to a real system. Practice requires the solution of a set of complex tasks. Thus, the variety of criteria causes serious difficulty to assess the object quality. Secondly, the characteristics of systems results in the dimension of description. Thirdly, there is a problem of adequacy of the system structure description. The problems are solved through ranking and aggregation. The adequacy of the model to a real system is reached by identifying the main components from the entire range, which determine the existence and behavior of the studied object.

The model is formed to solve the specified tasks; therefore, it is necessary that each task has its corresponding model (simpler than the original). The necessary compromise between complexity and adequacy is reached via iterations. In practice the complexity of models is reduced through special methods such as:

- aggregation;

- giving variables the status of constants for some range of value variation;

- change of functional dependence of one type to another;

- restriction of model accuracy.

The authors suggest to conduct model studies following an algorithm, which includes the following stages: problem statement, preliminary (“premodel”) analysis, model creation, search for solution, model check, assessment of results.

The first step includes the following stages and operations:

- problem statement;

- definition of the purpose of modeling;

- collection of information on the modelled system;

- identification of factors influencing a system.

Problem specification defines the purpose as the result of work on system modeling. The comparative analysis of the planned purpose with resource restrictions allows formulating tasks of model research. In the course of “premodel” analysis the existing object, technical means of modeling and application programs are analyzed.

The third step includes the following stages:

- formation of model structure and composition;

- development of operational algorithm;

- model arrangement from a set of private models;
- formation of relations between submodels;
- system organization of a complex object model;
- synthesis of model characteristics.

The stage of solution search represents the definition of criterion function. At the same time, according to known fundamental provisions the indicators of modeling result are formulated as components of a complete solution. Then the type of utility function is defined.

The stage of model check, first of all, assesses the adequacy of the developed design. Models shall be checked by answering the following questions:

1. Whether the model includes all essential properties?

2. What is the correctness of functional relations between components?

3. Whether restrictions on model parameters are correct?

To assess the compliance of a model to a real system it is advisable to use the following methods:

- comparison of model results to experimental data;
- comparison with models analogs;
- comparison of model structure to characteristics of the original.

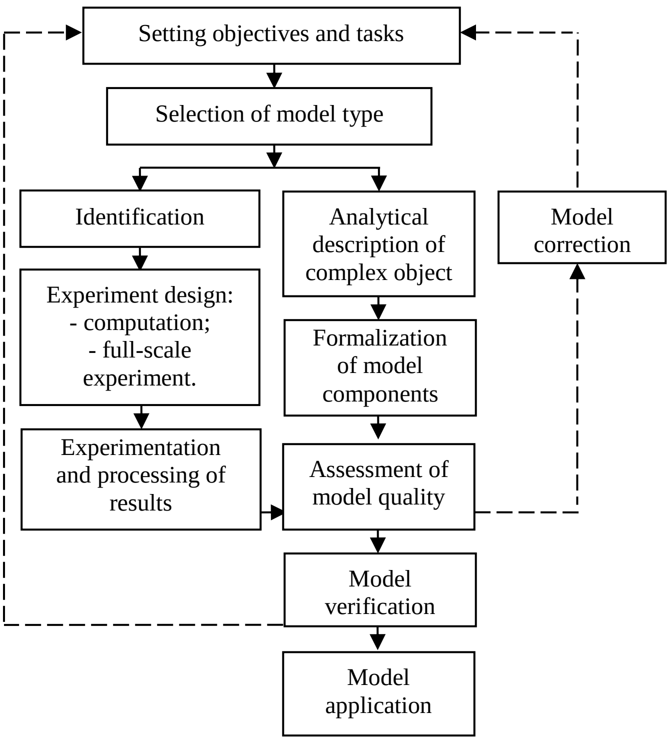

Fig. 1. Scheme of model formation of a complex system

The main criterion to check the adequacy of the designed model is practice. The results of comprehensive check trigger further processes:

- decision on the possibility to use the model in practice;
- correction of the model.

In the majority of cases the model is subject to correction operations. Such situations happen due to “scientific uncertainty” connected with multifactority of system properties and external influences. The process of model correction includes the following operations:

- specification of parameters,
- revision of restrictions for the range of characteristics,
- specification of forecast indicators of system behavior;
- profound analysis of relations between components.

The essence of optimization is the maximum possible simplification of models at specified adequacy level. The scheme of model development is shown in Figure 1.

The conclusion on the compliance of the received model parameters to real objects is made on the basis of the analysis of modeling results. In case the established requirements are satisfied the model materials are used for development and adoption of management decisions in the field of technosphere safety.

III. Results

The study described in the previous section was used for modeling of environmental safety of the region, within which the industrial enterprises function. The assessment of natural and technical system (NTS) represents a relatively complex object for study. NTS complexity is caused by its characteristics and behavior in space-time coordinates. The first factor defining the complex structure of the considered system is that it consists of a set of diverse, in terms of size and property, natural and technical objects. The second aspect causing complexity of the study is connected with the first factor and is defined by the fact that the plurality of properties and large number of relations between NTS parts generates new properties of a system. This process can be illustrated with the model shown in Figure 2.

The third feature of natural and technical system is that it continuously develops, i.e. represents a dynamic system. Therefore, such natural and technical systems belong to the class of complex, more precisely, structurally complex systems. In this regard the objective results of NTS study can be received using the system analysis.

It shall be noted that a difficult aspect of modeling is the introduction of time parameter to model characteristics. Satisfactory results are obtained using the series of observations grouped in the chronological sequence or static approximations. But the bulkiness of such models does not allow conducting detailed analytical studies, including identification of parameters and check of model adequacy. An alternative to multidimensional models is the development of a complex of private models. The detailed consideration of the situation with private models specifies the disadvantages of in this technique:

- large number of tasks requiring the solution using one model;

- nontransparent structure and approximate parameters of a model;

- unclear relations between subsystems.

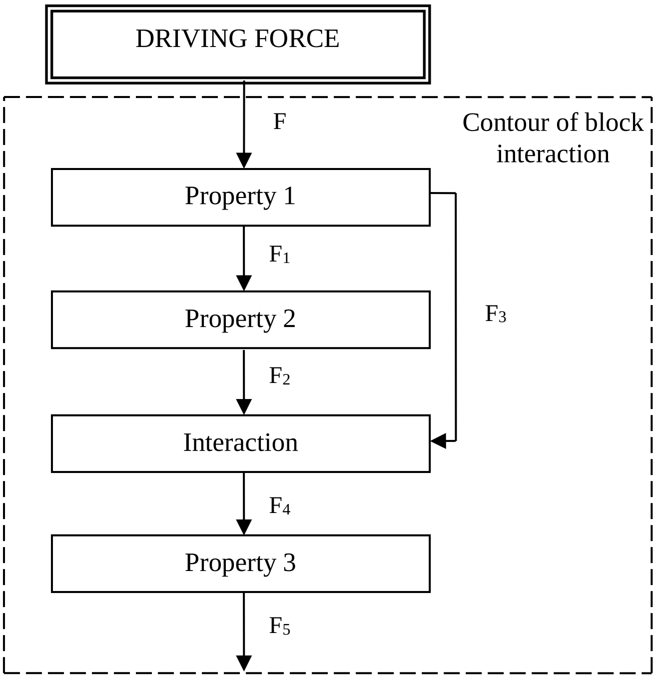

Fig. 2. Diagrammatical model of interaction of objects within the ecosystem

For NTS modeling it is suggested to use the technique based on the use of a complex of indicators and the modernized NTS model. This model represents the synthesis of a technical system model and the model of the environment. It is known that natural and technical systems were developed due to economic activity of a person and serve the source of all major environmentally harmful and dangerous factors (HDF). The results of the study show that multidimensional interaction of HDF leads to violation of spatial and functional stability of structures, and, therefore, to the transition of a system to a new, unstable state [11]. The two-component model allows solving a number of theoretical and practical tasks related to the assessment of anthropogenic impacts on the urbanized territory with the necessary degree of reliability. At the same time the model of impact of a technical subsystem on SE can be presented as a flowchart (Fig. 3).

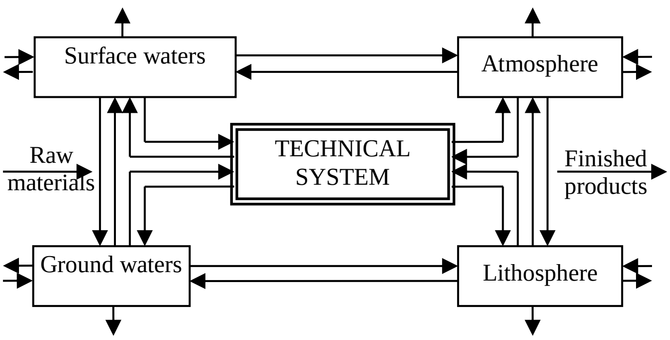

Fig. 3. Scheme of technical system impact on the environment

The flowchart shows that the technical system exerts complex negative impact on OS elements. The OS model is adjusted when it receives information on the condition of the environment and its dynamics concerning a set of indicators. At the same time the main components of this model are water, air, underlying surface, as well as resources and industrial and consumption wastes. Then three components shall be included into the model: physical, chemical and biotic, as well as directions of study (structure, processes, properties and phenomena). The following characteristics are used as indicators:

- indicators of anthropogenic influence;

- state indicators;

- indicators of social response.

The specified indicators are attributed to the main components: air, water and lithosphere. Besides, there is a need to formulate the general criteria to select indicators in systems to ensure the management decisions:

- importance of an indicator for the territory;

- suitability for use in databases;

- possibility of compatibility with the system of decision-making.

In the course of modeling it is important to formulate the aggregated indicators representing the sum of indicators of one type. For example, the integrated air pollution indicator is introduced for atmospheric air. The formulated indicators will present the OS quality assessment criteria. The analysis showed that the estimates made using the indicators are objective. At the same time all arising effects of negative impact of industrial facilities are fixed thus allowing assessing environmental risks for the region.

The above aspects of NTS modeling allow recommending this technique for practical application. At the same time the modeling shall be carried out in three stages (Fig. 4).

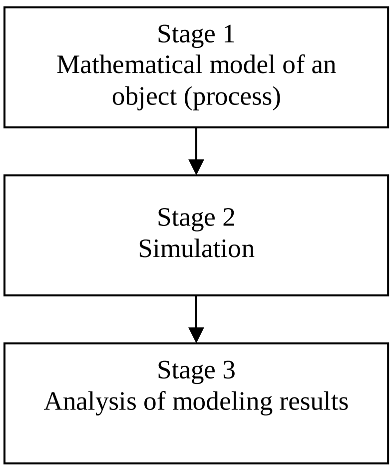

Fig. 4. Flowchart of simulation modeling of complex objects

Experts in the field of life safety are interested in the potential of the urbanized territory to adopt the justified management decisions. In this regard, the simulation modeling (SM) serves the indispensable analytical tool. Figure 5 shows the scheme of environmental safety forecasting using SM.

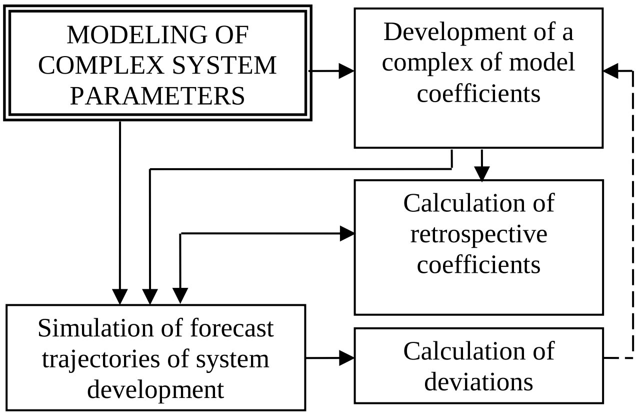

Fig. 5. Scheme of NTS condition forecasting using simulation modeling

The choice of the simulation method is proved by the fact that it allows considering such various factors as nonlinearity of characteristics of elements, accidental influences of external environment and other aspects.

IV. Conclusion

The scientific and methodical developments presented in this paper provide for correct modeling of objects and technosphere processes formed in the course of production and economic activity in a particular territory.

The received tuple of models allows making objective assessment of the state and perspective forecast of environmental safety in the region. The use of forecast information obtained via modeling allows making optimal management decisions on the creation of comfortable environmental conditions for the population. It is important to note that environmental and economic efficiency of this development is confirmed by practical assessment of environmental situation in the territory of the Rostov Region. Following the results of comparative analysis of forecast and actual data performed in the region, the reliability of forecasts makes 85% [11].

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