System simulation of environmental safety in Russian regions with developed railway infrastructure

Natalia Khamidullina1*, Mikhail Molev2, and Anastasia Opatskikh 1

1Princeton Rostov State Transport University, 344038 Rostov-on-Don, Russia
2Institute of Service and Entrepreneurship (branch) Don State Technical University in Shakhty ISO and P, 346500 Shakhty, Russia

Abstract. The article presents the results of research on simulation of objects and processes in order to predict environmental safety in Russian regions with a developed railway network. It is shown that sources of environmental pollution form a complex technogenic system that initiates the development of qualitatively new negative processes that significantly affect the living conditions of the population. The complex structure and ecological impacts have determined the development of innovative methods for analysis of environmental safety in the territories under consideration. The objective of the studies outlined was to develop a rational set of simulation procedures to provide reliable forecast as an informational basis for making effective decisions on managing the ecological condition of the regional environment. The problem was solved by joint use of mathematical methods of analysis, synthesis and synthesis of the received materials.

1 Introduction

The relevance of the problem of ensuring environmental safety has increased significantly in Russia's industrial regions, including areas with a developed railway network. Regular intensive railway traffic and the economic activities of enterprises that provide the necessary level of logistics generate a number of significant negative impacts on the population and the surrounding natural environment (SNE). In particular, the environmental situation in such anthropogenically loaded regions is characterised by a high level of SNE pollution by various harmful substances, of organic and inorganic origin, such as dust, soot, carbon monoxide, sulphur dioxide and nitrogen dioxide. The reduction of the concentration of harmful substances in the territories under consideration necessitates the implementation of organizational and technical measures to improve technological processes. In turn, the development and adoption of management decisions should be based on reliable information about the characteristics and parameters of negative impacts associated with economic activities of the railway complex.

Currently, scientific research on the technogenic impacts of the Russian railway complex on SNE is fragmentary, which reduces the value of the information obtained. A. Pronin

* Corresponding author: opatskih@yandex.ru
considers only pollution of the environment by acoustic fields [1]. D. Kurepin assesses the environmental situation in the framework of cargo transportation [2]. A. Pavlov, V. Pashinin and M. Kovalenko in their scientific works outline the results of studies on the impact of technological processes on the hydrosphere [2, 3]. N. Osipova’s publications are devoted to the study of technogenic hazards for SNE linear structures [4]. Particular issues of the negative impact of industrial facilities, including railway transport, are outlined in the scientific works of other researchers [4-7].

In the belief of the authors of the article, substantiated by the results of many years of research, reliable information can only be obtained by a systematic full-scale study of all factors that are caused by the production facilities [8, 9].

2 Materials and Methods

The objects of the railway complex, which significantly determine the state of technosphere safety in the adjacent areas, form a very complex hierarchical system with a set of multidirectional interdependent relations. Based on this notion, it is correct to propose a methodology, including system simulation, for solving environmental safety problems. Building models of objects and their impacts is a significant stage in the study of technogenic hazards of railway transport. The results of the subsequent analysis of the behaviour of real objects largely depend on the quality of the developed models.

Based on their experience in simulating technogenic hazards, the authors performed all simulation procedures using integral systems analysis (ISA). This choice is due to the fact that the application of ISA provides in practice the implementation of the fundamental properties of any technical system. According to the author's strategy, the simulation process addresses the following basic tasks: dimensioning of the object, development of structural characteristics and joint evaluation of the results of the first two procedures.

Simulation of complex systems is usually associated with the development of a tuple of models of hierarchical nature, which differ in the level of mapped operations. In this case, an integral procedure of the process is to identify subsystems and control objects as levels of the system. The implementation of ISA in the formation of the necessary model set of objects stipulates the performance of analytical operations, such as a detailed study of the initial parameters of the hazard source and the environment, and an analysis of the functioning of the technical system. Researchers in simulation objects of complex structure must find acceptable solutions to a set of problems, including the selection of a set of criteria, determination of the dimensionality of characteristics, assessment of the adequacy of the model to the real structure. It is logical to solve these problems using mathematical procedures of ranking and aggregation. Adequacy assessment is based on the analysis of characteristics that form the spatial and temporal behaviour of the investigated source of environmental hazard and is achieved by finding reasonable answers to a set of questions, including:

- completeness of inclusion of the defining properties of the object in the model;
- correctness of reflection of logical and functional relationships between the elements of the system;
- fairness of restrictions placed on the parameters of the model under control.

On the basis of available experience, the algorithm of simulation of objects of ecological threats SNE, containing stages: a problem statement, the preliminary analysis, development of model of danger, search of the decision, check of adequacy of model, an estimation of reliability was used.

The results of comprehensive verification determine further work: a decision is made whether the built model can be used; adjustments to the model are made.

In the second case, the following logical-mathematical operations are carried out:
- modification of some parameters of the model;
- correction of restrictions imposed on the area of existence of characteristics;
- detailed analysis of relationships between elements and subsystems.

As a result of the analysis of the practice of simulation various production facilities and their technogenic impact on SNE, the following simulation flowchart was developed (Fig. 1).

Detailed and comprehensive analysis of the results of model studies allows to formulate scientifically valid conclusions on the compliance (non-compliance) of selected parameters and characteristics of model structures to the object under study. In case the specified requirements are met, the obtained materials are used in developing and making managerial decisions in the sphere of ecological safety in the given territory from the enterprises of the railway complex located in it.

![Fig. 1 Block diagram for simulation a production facility of a railway complex.](image)

### 3 Results

The research material described in the previous section has been used to model the environmental safety of regions within which production facilities operate, including various sources of negative environmental impact that belong to the railway infrastructure.

It should be pointed out that assessing the environmental safety of such a natural and technical system (NTS) from the perspective of process analytics is considered a rather difficult task in scientific circles, due to the complexity and scale of this artificial entity. This starting point is due to a number of real inherent structural and behavioural factors inherent in NTS.

First of all, such factors include the design of the system under study, which is formulated by a set of subsystems (elements) characterized by radically different geometric dimensions and properties.
A logical analysis leads to the conclusion that the described aspect of NTS is the source of new properties of the object as a system that possesses emergent nature. This fundamental conclusion should be considered as the second aspect characterising the complexity of model formation. The indicated relationship and behaviour of the production infrastructure is depicted in the block diagram of the model (Figure 2).

![Block diagram of the model](image)

**Fig. 2** Block diagram of the model of interaction of anthropogenic factors in a complex production facility: F – factor.

The fact that the processes of negative environmental impact of railway companies are dynamic means that it is necessary to add the "timing" characteristic to simulation. In this respect, practice has shown that the correct way of solving the issue is to use "observation-time" matrices arranged in a strict chronological sequence. But the considerable cumbersomeness of such a model does not allow detailed analytical studies including identification of parameters and checking its adequacy. As an alternative to multivariate models, a rational set of partial models can be generated. However, a detailed consideration of this methodology reveals significant shortcomings:

- a large number of problems to be solved;
- obtaining approximate model parameters;
- fuzzy representation of inter-element relationships.

Based on the results of the analysis, the authors propose an original methodology for constructing a model of the habitat in areas where railway facilities are located. The basic idea of the simulation work is to apply to solve the problem of interconnected combination of condition indicators and two-component synthesized NTS model. This model is formed by means of synthesis of two approximations: complex of industrial objects and natural environment. The proposed two-component NTS model, formed by analyzing anthropogenic impacts, is based on the actually established fact of the region's security transition to a new unstable state [9]. The approach provides a correct solution to a set of scientific and technical questions within the framework of assessing the negative impact of production facilities. A generalized model of technogenic impact of enterprises and infrastructure on the environment is shown in Figure 3.
From the presented flowchart, it is clear that the technical part of the NTS has a complex negative impact on all elements of the habitat. The developed model allows making adjustments for changes in the state of the NTS using a set of indicators. As the main indicators, such characteristic features are proposed as:
- criteria of anthropogenic impact of production facilities;
- parameters of the current state of habitat;
- indicators of societal response.

The listed indicators are attributed to all components of habitat: air, hydrosphere and soil. As part of the simulation exercise, it is mandatory to establish the rules for selecting criteria to ensure optimum management decisions on habitat safety. The following basic criteria are proposed:
- quantitative assessment of the importance (significance) of the anthropogenic factor for the region under study;
- possibility of applying the proposed indicator in the calculations;
- compatibility of the indicator with the management decision-making methodology.

Analysis of the results of the model studies has shown the urgent need to form the so-called "aggregated" indicators for one habitat component. The proven Atmospheric Pollution Indicator (API) is noteworthy. Such aggregated indicators quantitatively characterise, in a model design, the quality of the habitat in areas where railway infrastructure facilities are located. A detailed evaluation of the application of the indicators has shown a satisfactory convergence of the model results with the actual materials. In general, the simulation should be carried out in three stages (Figure 4).
Fig. 4. Block diagram of complex object simulation.

The main conclusions presented in the section as research findings on environmental safety simulation provide an objective justification for recommending the proposed methodological development for application in the NTS management system.

4 Results and Discussion

In the presented work, the authors have implemented the main scientific and methodological approaches obtained as a result of numerous scientific studies on the problem of ensuring environmental safety of habitat under conditions of high technogenic load on NTS. One of the problems was justification and development of effective simulation methodology, which takes into account the whole set of technogenic impacts of the production complex. As a result of materials analysis, the choice of analytical tools and simulation algorithms was confirmed, which allow performing simulation works qualitatively. Thus, the proposed methodology differs from the materials outlined in the publications of the authors mentioned in Section 1, a comprehensive approach to solving the problem.

As a direction for further research, the development of improvement of the methodology in the direction of its adaptation for other industries, as well as optimization of the hardware software complex is considered.

5 Conclusion

The scientific and methodological elaborations presented in this article allow for a sufficiently correct and prompt simulation of railway infrastructure facilities and technogenic impacts that are observed in a particular territory. On the basis of the developed tuple of models of enterprises and associated negative processes, environmental safety specialists can make a reliable assessment of the actual state of the environment in the territory in question, as well as develop a forecast conclusion on the development of the situation in the future. In this direction, the authors emphasize the fact that all theoretical and methodological proposals have been tested in the practice of environmental services of municipalities and production enterprises. According to the results of comparative analysis of predictive and actual materials carried out for the technogenic-loaded Rostov region, the reliability and reliability of prospective forecasts is 80-85% [9].
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