METHODOLOGY OF ASSESSING TERRITORIAL RISKS OF THE ARCTIC ZONE OF KRASNOYARSK REGION IN THE IMPLEMENTATION OF INVESTMENT PROJECTS

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Abstract

The work is aimed at developing effective methods and models for solving problems in the field of analyzing the safety and security of Northern and Arctic territories in the context of multifactorial impacts (intensified development, implementation of investment projects, climate change), including identification of hazard factors, assessment of current and future man-made risks and security. To establish cause-and-effect relationships of the hazard factor's impact on the safety and sustainability of territories, it is proposed to use probabilistic graphical models based on Bayesian networks. The work was tested using the example of the Arctic territories of the Krasnoyarsk Region.

Keywords: climate change, technogenic hazards, territorial risks, safety

I. Introduction

One of the key problems of our time is adaptation to climate change. The international community is making attempts to solve this problem at the global level (Kyoto Protocol, Paris Agreement on Climate), but no significant results have been achieved. The problem is especially acute in the Arctic Zone (AZ), which is the most vulnerable territory to climate change.

According to the forecasts of the Intergovernmental Panel on Climate Change (IPCC), in the foreseeable future the Arctic territories may face the following problems [1-3]:

- - reduction in the extent of sea ice in the Arctic Ocean;
- - degradation of permafrost;
- - melting of the Greenland ice shield;
- - northward shift of the boundaries of natural zones and habitats of biological species.

One of the key problems of socio-economic development of the Arctic territories is associated with the melting of permafrost [3]. In the Strategies for the Development of the Arctic Zone and the Siberian Federal District of the Russian Federation for the Period up to 2035 [4, 5], from the standpoint of ensuring national security, one of the key factors influencing socio-economic development is changing climatic conditions, which contribute to the emergence of both new economic opportunities and risks for economic activity and the environment. Climate change leads to a decrease in the load-bearing capacity of buildings and structures, the integrity of industrial facilities and critical infrastructure is disrupted, which leads to the emergence of additional natural and man-made hazards, as well as significant economic losses associated with a reduction in service life, costs for maintenance, repair and reconstruction, and replacement of equipment earlier than planned. Accidents that occur in the networks of telephone, water or electricity supply can lead to serious consequences, up to and including the decision to evacuate the population [6, 7]. In these conditions, issues of technogenic safety acquire primary importance, since they determine the prospects for the development of territories, which makes research

absolutely relevant.

The purpose of this work is to analyze technogenic safety in the implementation of investment projects taking into account natural and climatic factors based on a risk-oriented approach with subsequent testing on the example of the Arctic territories of the Krasnoyarsk Region.

The Arctic zone of Krasnoyarsk Region has a number of features:

- the climate of the territory belongs to the absolutely uncomfortable zone (the average annual temperature in January is -50°C);
- the landscape of the territory is represented by the Arctic desert, tundra and forest-tundra;
- a significant part of the territory is glaciers and permafrost (up to 46.2% of the total area of the Krasnoyarsk Region);
- active industrial development: mining, fuel (oil and gas), metallurgy, food industries, production and distribution of electricity, gas and water.
- high frequency of dangerous natural phenomena (storms, hurricanes, squalls, snowfalls, heavy ice, frost, blizzards, fog, frost, avalanches, heavy waves, coastal ice breakaway, floods, low water levels, early freeze-up, wildfires, etc.).
- high man-made load (occurrence of accidents in transport systems, industrial facilities, life support systems).

The Arctic zone of Krasnoyarsk Region includes 4 municipalities: Norilsk, Taimyrsky Dolgano-Nenetsky, Turukhansky and Evenkiysky districts. The total area of the AZ is 1854.5 thousand km², where more than 230 thousand people live.

Most of the Arctic territories are only subject to development, the main economic activity is concentrated in populated areas and along linear objects of transport infrastructure, thus climatic features and man-made load lead to destabilization of the natural system, to the emergence of environmental problems and a decrease in the quality of human life in extreme living conditions. In this situation, ensuring natural and man-made sustainability, increasing the security of the population and territories is possible only with an integrated approach to planning and managing development risks [8].

II. Methods

For sustainable development and functioning of territorial systems in conditions of multifactorial impact (intensified development, implementation of investment projects, climate change, etc.), it is necessary to analyze and assess both current risks and possible new threats.

Figure 1 shows a step-by-step scheme for analyzing the safety of a territory during the implementation of investment projects.

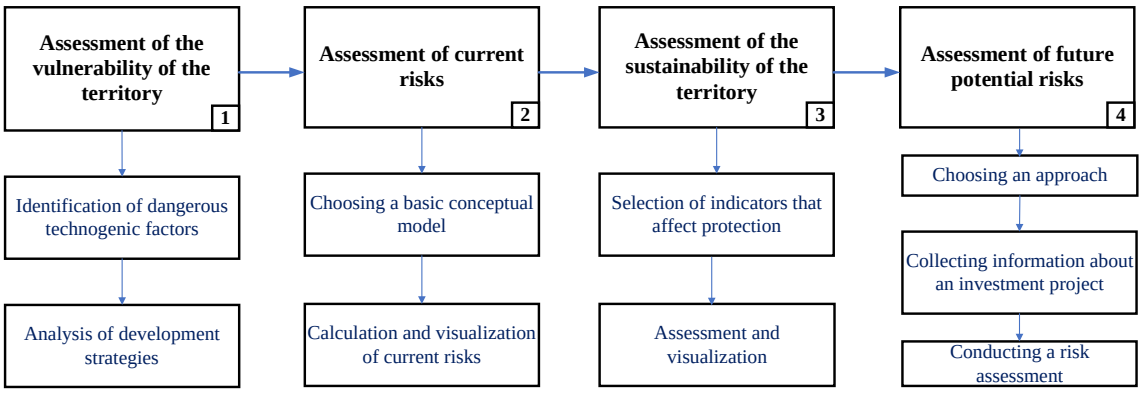

Figure 1: *Area Security Analysis Scheme*

At the first stage, when assessing the vulnerability of the territory, it is necessary to identify existing hazardous factors and analyze development strategies (activities) aimed at attracting new investors and stimulating industrial production.

At the second stage, when assessing current risks, it is necessary to select a mathematical model. In the work, to establish cause-and-effect relationships of the influence of hazard factors on the safety and sustainability of territories, it is proposed to use probabilistic-graphical models based on Bayesian networks. Bayesian networks combine the mathematical apparatus of probability theory and graph theory [9-11]. The basic idea of constructing a graphical model is related to the concept of modularity, i.e. decomposition of a complex system into simple elements. The probability of an event for each graph is determined by the formula for total probability. If event A can only occur when one of the events B_1, B_2… B_n, which form a complete group of incompatible events, is executed, then the probability of event A is calculated using formula (1):

$$P(A) = P(B_1) \cdot P(A \mid B_1) + P(B_2) \cdot P(A \mid B_2) + \cdots + P(B_n) \cdot P(A \mid B_n) \quad (1)$$

To calculate the conditional probabilities of a given event, the Bayes formula (2) is introduced:

$$P(A \mid B_i) = \frac{P(B_i) \cdot P(A \mid B_i)}{P(B_1) \cdot P(A \mid B_1) + P(B_2) \cdot P(A \mid B_2) + \ldots P(B_n) \cdot P(A \mid B_n)} \quad (2)$$

The assessment of the current risk for each hazardous factor is determined on the basis of the obtained values of probability and damage (3):

$$R_t = P_i \cdot U_i \quad (3)$$

where P_i is the probability of occurrence of a certain risk factor; U_i is the damage from a certain risk factor, million rubles (data obtained from the official database of the Russian Emergencies Ministry).

At the third stage, we determined the sustainability (protection) of the territory. Technogenic protection of the territory is understood as a set of factors and measures that ensure the safety of the technosphere in the event of emergencies and disasters. Table 1 presents a list of indicators that affect the sustainability of the territory to occurrence of hazards.

Table 1: *Sustainability (protection) indicators*

List	Normative values	Normative documents
Fire departments	Estimated ratio of the dependence of the rescuers number on the population density	Organizational and methodological recommendations for determining the number of firefighting services of a constituent entity of the Russian Federation and its technical equipment
Emergency rescue teams	Calculated ratio of the dependence of the number of formations on the number of hazardous industrial facilities	Order of the Ministry of Health of the Russian Federation dated 27.02.2016 No. 132n "On the requirements for the placement of medical organizations of the state healthcare system and the municipal healthcare system based on the needs of the population"
Medical organizations	Depending on the population size	Orders and Decisions of the subjects of the Siberian Federal District "On approval of the list of potentially dangerous objects".

Quantitative values of protection are determined on the basis of the proposed formula (4):

$$Z_{(\tau)} = \frac{1}{3}\left(\frac{N_{\text{FD}}^{A}}{N_{\text{FD}}^{S}} + \frac{N_{MO}^{A}}{N_{MO}^{S}} + \frac{N_{ER}^{A}}{N_{HIF}^{A}}\right) \cdot 100 \geq 100\% \quad (4)$$

где N_{FD}^{A}/ N_{FD}^{S} – actual/standard number of fire stations in the territory under consideration; N_{MO}^{A}/ N_{MO}^{S} – actual/standard number of medical institutions in the territory under consideration; $N_{\text{АСФ}}^{\Phi}$ - the actual number of emergency rescue teams in the territory under consideration; N_{HIF}^{A} - the actual number of hazardous industrial facilities in the territory under consideration..

At the fourth stage, it is necessary to assess the possible risks from the implementation of investment projects in the territory under consideration. It is recommended to analyze possible hazardous events using probabilistic-graphical models, which allows assessing the combined impact of current and future risks.

III. Results

For the Arctic zone of Krasnoyarsk Region, the main dangerous man-made factors were identified, presented in Figure 2. Based on this graphical model, the probabilities of occurrence of events and risk values for each factor are determined. According to the proposed algorithm, state programs and plans for the development of the Arctic zone of Krasnoyarsk Region were further analyzed, which are aimed at creating a regional transport and energy infrastructure, and forming high-tech and competitive territorial clusters.

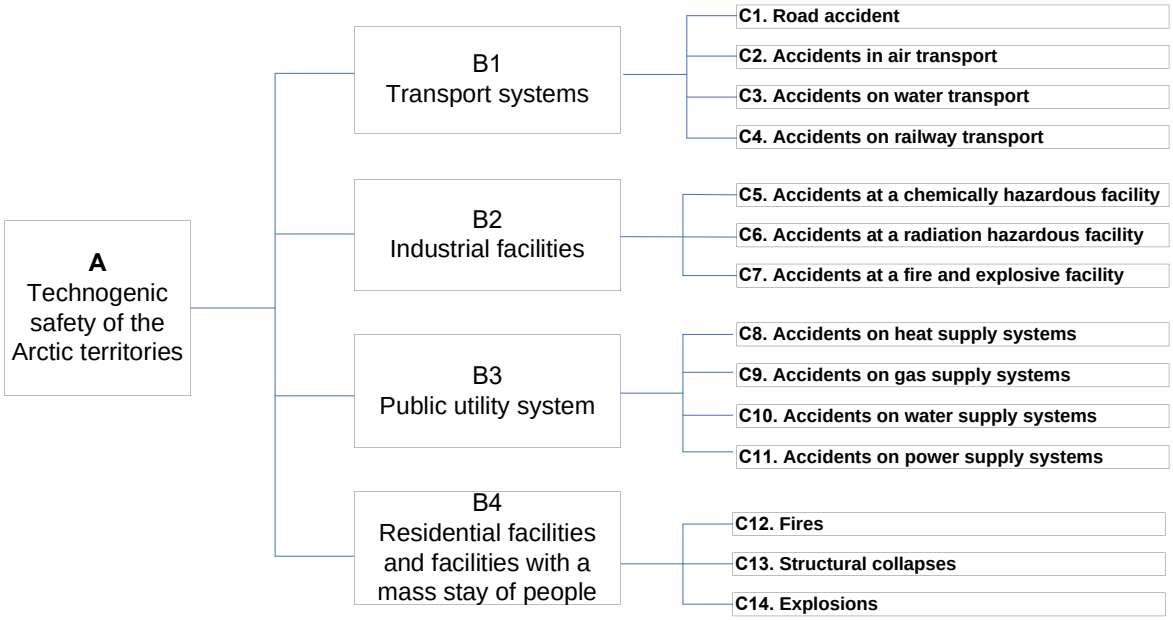

Figure 2: *List of man-made hazards*

Key investment projects for the development of the Arctic zone of Krasnoyarsk Region include [4]:

- creation of a network of latitudinal and meridional railways;
- development of the infrastructure of the Northern Sea Route;
- creation of a new large mining and metallurgical complex in the Norilsk industrial region - the "Southern Cluster" Project;
- development of oil and gas fields;
- gasification of the Krasnoyarsk agglomeration based on the associated gas resources of Evenkiysky district;

- renovation of the housing and communal services of the Norilsk agglomeration;
- development of Arctic and northern tourism.

To assess the current territorial man-made risk, it is necessary to determine the probability of a hazardous event. Figure 3 shows probability distribution diagrams for event groups.

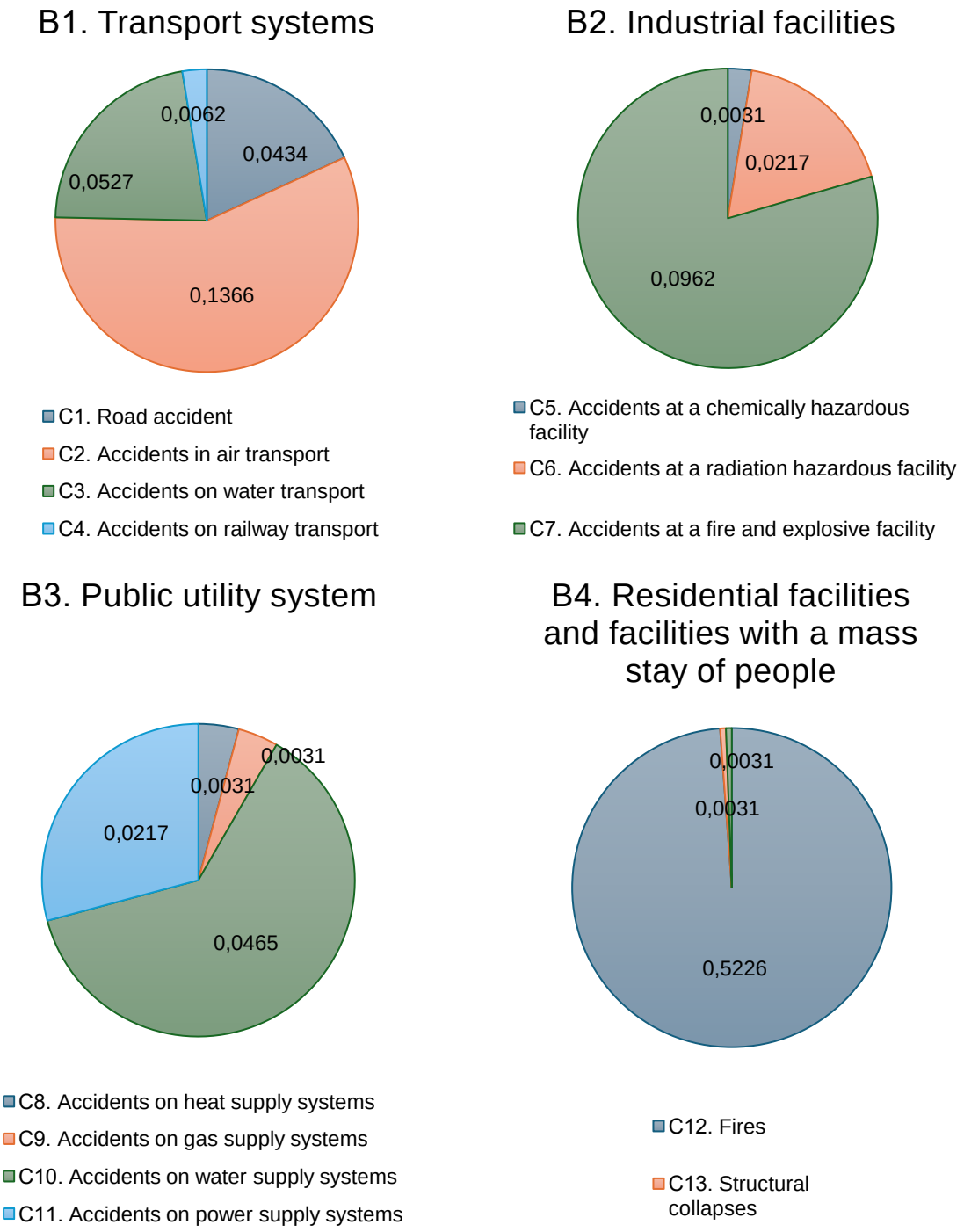

Figure 3: *Probability distribution across event groups*

Based on the obtained results of probability calculation, it can be concluded that the most frequent occurrences are fires, accidents on air transport, at fire-explosion hazardous facilities and on power grids.

Table 2 presents the results of the assessment of territorial man-made risks for each municipality of the Arctic zone and the level of protection.

Table 2: *Territorial man-made risk of the Arctic zone of Krasnoyarsk Region*

The name of the main factors	**The risk of a dangerous factor**			
	Taimyrsky Dolgano-Nenetsky district	Evenkiysky district	Turukhansky district	Norilsk city
Transport systems	$4{,}8\cdot10^{-2}$	$5{,}2\cdot10^{-2}$	$3{,}6\cdot10^{-2}$	$8{,}1\cdot10^{-2}$
Industrial facilities	$6{,}1\cdot10^{-3}$	$3{,}7\cdot10^{-2}$	$1{,}2\cdot10^{-2}$	$6{,}4\cdot10^{-2}$
Public utility system	$1{,}2\cdot10^{-2}$	$1{,}5\cdot10^{-2}$	-	$4{,}3\cdot10^{-2}$
Residential facilities and facilities with a mass stay of people	$3{,}9\cdot10^{-2}$	$1{,}4\cdot10^{-1}$	$6{,}5\cdot10^{-2}$	$3{,}03\cdot10^{-1}$
	The level of protection of territories			
	17%	37%	34%	39%

The Taimyr Dolgano-Nenets and Turukhansky districts are at risk of air transport accidents. The Evenki district has the highest risk of household fires. The greatest man-made hazard is concentrated in Norilsk, which is due to the high population (in comparison with municipal districts), the number of potentially dangerous objects and the intensive traffic of the Norilsk airport. Having identified the dangers arising in the territory, it is necessary to analyze its ability to withstand threats. Municipalities of the Arctic zone have a low level of protection. For the city of Norilsk, Taimyrsky Dolgano-Nenets and Turukhansky districts there are not enough emergency rescue teams, fire departments and medical institutions. For the Evenki district there are not enough fire departments and emergency rescue teams.

When assessing possible future man-made risks, we will consider the emergence of additional threats associated with the creation of a large mining and metallurgical complex in the Norilsk industrial region. We will consider a common scenario of a fire and explosion associated with blasting operations. Fig. 4 shows a probabilistic graphical model for analyzing this scenario.

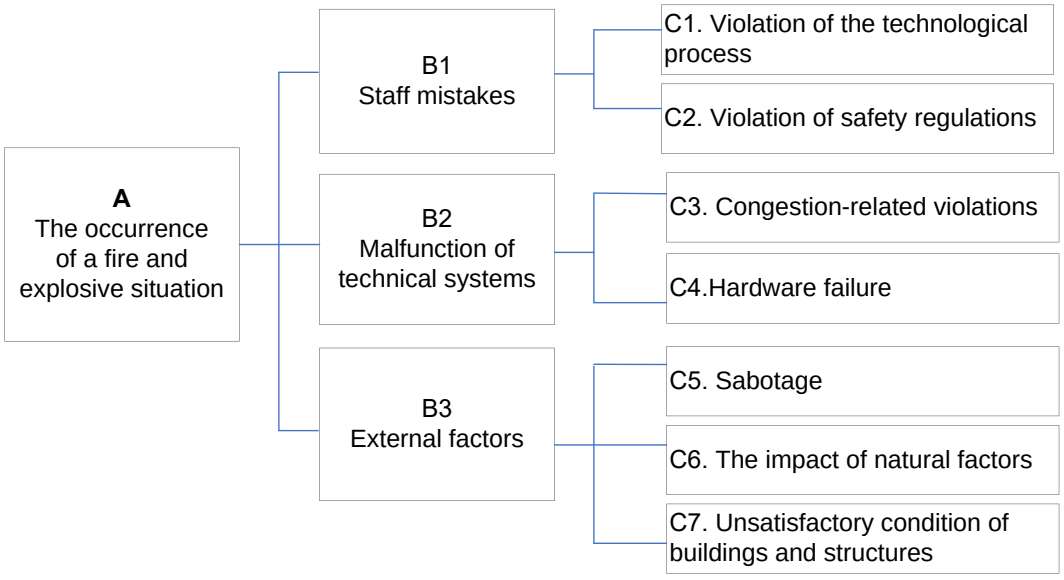

Figure 4: *Cause-and-effect patterns of occurrence of a fire-explosion hazardous situation*

The probability of occurrence of a fire and explosion hazardous situation is 5.6·10-6, the damage from the implementation of this scenario is about 200 million rubles. Thus, the territorial man-made risk from the occurrence of industrial accidents for the city of Norilsk increases from 6.4·10-2 to 6.51·10-2 and this is taking into account one possible accident scenario. Thus, with an insufficient level of protection, high current man-made territorial risks, the implementation of investment projects should be carried out with increased control by the state. Development and exploration of territories should be without damage to future generations.

IV. Discussion

Active industrial development of northern and arctic territories, the development of infrastructure projects and clusters, taking into account special natural and climatic conditions leads to a dilemma between economic growth and an increase in the number of potential dangers associated with the growth in the number of industrial facilities.

Thus, the management of territorial entities should be based on the methodology of risk and security assessment within the framework of the concept of sustainable development and the leading priority of the socio-economic and scientific-technical development of Russia - the security of society and the state. Prevention of hazards can be effective only with the development of a methodological complex of territorial analysis based on a risk-oriented approach.

Man-made systems, natural processes, and territorial formations are subject to the impact of characteristic types of risk that must be specifically identified and necessary measures taken to protect and mitigate the consequences in the event of a hazard, which is especially important for Arctic territories with unique natural complexes, the impact on which can lead to catastrophic consequences.

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