Analysis of climate risks impact on railway infrastructure and adaptation measures system development

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Abstract. Analysis of the impact of climate risks on railway infrastructure and development of a system of measures to adapt transport infrastructure to climate change. The object of the study is Russian transport infrastructure, analyzed using the method of identifying the peculiarities of the functioning of the transport infrastructure, taking into account regional specifics. An analysis of climate risk factors, the effects of climate risk factors, as well as the impact on railway infrastructure was carried out with the aim of integrated management of natural hazards and the development of adaptation measures to climate change. It is shown that improving measures and strategies for adapting railway transport to a changing climate may include the following systems: a system for preventing accidents and incidents; monitoring system for environmental parameters and infrastructure facilities; measures to protect railway transport facilities; introducing changes to production standards; relocation of infrastructure facilities when it is impossible to operate them in a given territory. Key words: climate change; transport infrastructure; adaptation; vulnerabilities; climate risk

1 Introduction

The significant service life of most transport infrastructure facilities and its critical importance for the functioning of the socio-economic system of a territory, region or country determines the need for its adaptation to the conditions of a changing climate. In the absence or untimely development and implementation of adaptation measures to climate change, global or regional climate processes may have a significant impact on the operational, financial, environmental and social indicators of fixed assets of transport infrastructure.

Adaptation of Russia's transport infrastructure to climate change is described in the Climate Change Adaptation Plan in the field of transport in accordance with the National Action Plan for the first stage of adaptation to climate change. The subjects of adaptation related to the railway industry are the construction of railways, intercity and international passenger transportation, and freight transportation [1].

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The objects and components of transport infrastructure are extremely diverse, they include energy facilities (electric networks, power plants), a network of railways and access roads, an information and communication network (data cables), artificial structures (bridges, tunnels). There are many relationships between objects and components of the transport infrastructure, and the failure of one object can lead to a cascade of failures and disruption of the connectivity of the transport system. Hazardous natural phenomena can affect the performance of or destroy several objects or components of transport infrastructure simultaneously [2–6].

Climate change is already impacting transport infrastructure, either through direct or indirect damage or by affecting the reliability of transport infrastructure components. This trend is likely to increase in the near future [7]. Major threats to infrastructure include damage or destruction caused by extreme weather events, the frequency and severity of which are increasing with climate change.

A number of objects and components of transport infrastructure may not be directly affected by climate risk factors, but may lose their functionality when exposed to secondary manifestations of climate risk factors.

The need for investment in infrastructure may increase in the coming decades, since in addition to planned design, construction, operation and restoration, adaptation costs will appear, and in some cases, conditions in the areas of design, construction and operation of transport infrastructure facilities will change [8].

Ensuring infrastructure resilience to climate change is an important early adaptation challenge. Changes towards investments in more climate–resilient infrastructure have the following features:

– investments involve higher initial capital expenditures to ensure sustainability and profitability throughout the life of the infrastructure;

– a higher risk of error in decision-making is expected due to the uncertainty associated with the effects of climate change in the long term;

– ecosystems provide a number of adaptation services (natural habitats on coasts or floodplains protect against landslides, erosion and destruction of the coastline), therefore, ecosystem protection may be less costly than investments in the development or adaptation of artificial infrastructure.

Also, the development of a set of measures to adapt transport infrastructure to the effects of climate change allows us to improve existing technologies, as well as make wider use of the adaptation potential due to the emergence of new engineering solutions or information technologies.

From a territorial point of view, the aspect of adaptation of transport infrastructure is also important, since a significant part of the interconnected infrastructure is concentrated in cities, the adaptation of urban and transport infrastructure can solve numerous intersectoral problems of functioning and development.

The infrastructure of all four modes of transport is subject to climatic pressure and is subject to appropriate adaptation policies: rail (railways), road (roads and motorways in general and specific cases of coastal and mountain roads), shipping (inland and maritime navigation, ports) and aviation (airports).

The current trend towards rising temperatures and sea levels is accompanied by an increase in the frequency and intensity of natural disasters (e.g. storms, heat waves, floods) and has a significant impact on the safety of transport infrastructure. At the same time, climate change affects the redistribution of transport flows, including as a result of changes in tourist flows, which also leads to a change in the needs of transport infrastructure. In addition, the vulnerability of the transport sector also depends on human behavior and societal changes. Since different modes of transport are affected by climate change in different ways, the type of mobility that people choose affects the vulnerability of the entire sector. Climate change is characterized by both negative and positive potential impacts on transport infrastructure (rail, road, shipping, aviation), depending on the region of location. Thus, the predicted increase in the frequency and intensity of natural disasters, such as heavy rainfall, snowfall, extreme heat and cold, droughts, may lead to a negative impact on transport infrastructure, lead to economic losses and disruptions in the transport industry.

2 Object and Methods

The object of the study is the transport infrastructure of Russia. Climate impacts on transport infrastructure vary depending on location, exposure to climate hazards, available adaptation potential, and the level of development of the region's economy. This is due to regional differences in the change in the frequency and intensity of extreme weather events in the long-term and medium-term climate change forecast (increasing temperatures, changes in precipitation, etc.). In this regard, measures to adapt transport infrastructure should be based on taking into account different trends and include different models of the impact of climate risk factors on transport infrastructure facilities.

Russia is characterized by great territorial diversity, in this regard, increasing the sustainability of transport infrastructure should be based on local or regional conditions.

Thus, urbanized areas have an increased sensitivity to extreme weather events, this is due to the high concentration of population, material assets and types of socio-economic activities, one of the foundations of which is the uninterrupted functioning of transport infrastructure.

Also, a number of climate changes are intensifying in urbanized areas, characterized by microclimate characteristics (temperature, wind, precipitation), with the implementation of the urban heat island effect.

Challenges to operating infrastructure in changing climates include the ability to operate under higher operating temperatures in the summer (with increasing frequency and intensity of heat waves), the need to protect built-up areas from flooding, and ensuring energy supply during demand peaks (cooling in “hotter” summers). , heating in the “colder” winter). Urban residents may also be particularly susceptible to vulnerabilities in transport infrastructure.

Transport infrastructure in coastal areas may not be built, damaged or destroyed due to sea level rise (from 0.18 m to 0.58 m by 2100 [9]), coastal erosion (which will be accelerated by rising sea levels and increasing frequency of storms) . In addition, rising sea levels could lead to coastal flooding and increase storm surge impacts, threatening coastal transportation infrastructure.

The functioning of transport infrastructure in mountainous areas may be disrupted due to an increase in the frequency and intensity of natural disasters (landslides, rockfalls, avalanches, floods). Most natural disasters are associated with an increase in ambient temperature, which leads to loss of glacial mass and subsequent morphological transformations, such as a decrease in snow cover, melting of permafrost and a change in the nature of precipitation. It is predicted that climate change will lead to a later seasonal snowfall, a decrease in snow cover, an earlier descent of wet avalanches and a shortening of the snow season.

3 Results

Climate change is already having a far-reaching impact on infrastructure and may partially jeopardize its operation and reliability. This trend is likely to intensify in the coming decades. The main threats to transport infrastructure facilities are damage or destruction caused by extreme weather events, which are intensified by climate change.

Climate change may also increase the need for investment in infrastructure facilities and affect the choice of location, design decisions, and operational features. In addition, to protect infrastructure facilities, it will be necessary to create additional structures designed to adapt to and mitigate the effects of climate change.

Ensuring the sustainability of infrastructure facilities is an important component of measures to adapt to climate change, while the implementation of these solutions can significantly increase the costs of designing, constructing, and operating facilities. It is also advisable to change existing approaches to making decisions on the development of the transport network, especially given regional differences in the implementation of climate risk factors.

Changes towards more climate resilient infrastructure investments present some specific challenges. First, they often have higher up-front capital costs, even if their climate resilience makes them more profitable over the lifetime of the infrastructure. Second, investors may calculate an additional risk premium for projects to develop climate resilient infrastructure, due to the uncertainty surrounding the implications of climate change in the long run. Third, ecosystems provide some critical services. Investing in protecting these habitats can be less costly than developing or adapting man-made infrastructure, but market structures or incentives are not yet sufficiently implemented to make such investments always profitable.

However, taking climate risks into account in investment and operational/management decisions may not only mean avoiding costs at a later stage, but also opening up new economic opportunities. Adapting infrastructure to the effects of climate change opens up opportunities if measures are taken at an early stage and expertise is developed. This includes new skills and technologies, as well as additional adaptations to enable infrastructure adaptation, such as new engineering practices or IT-based technologies. What is a risk for urban planners, utilities, businesses and homes can in turn become an opportunity for those who build and maintain infrastructure. This knowledge and experience can also be an important asset in global competition and exported to other parts of the world.

From a territorial point of view, the urban dimension of infrastructure adaptation is crucial. Since a large proportion of important, often closely interconnected infrastructure is concentrated in cities, urban adaptation must solve a large number of numerous problems in the development and operation of infrastructure.

The development of a set of measures to adapt to a changing climate should be based on the following principles. First, taking into account predicted climate change scenarios, including regional specifics, when choosing a location, developing design documentation, and adjusting the practice of operating infrastructure facilities. This is especially important in the case of large infrastructure, which usually has a service life of at least 20 years, and investment decisions thus affect the well-being of future generations. Secondly, existing infrastructure can be made more resilient to climate change by upgrading and/or ensuring that maintenance regimes include resilience to the effects of climate change over the life of the asset.

The design thresholds that are embedded in infrastructure design solutions may be violated more often in the future with climate change. Climate change may cause failure thresholds that were once considered exceptional but acceptable to become common (i.e. normal) and unacceptable. The infrastructure may have to operate within narrower limits between "normal" operation and critical thresholds. This can manifest itself in reducing the efficiency of the equipment and providing less margin for error before drastic management measures (such as reducing operation or throughput) need to be implemented.

Infrastructure is generally constructed in a manner that is resilient to the weather conditions of the past. Climate change makes it increasingly important to enhance and disseminate knowledge on the present and future climatic conditions.

Examples from the energy sector show that different types of infrastructure are built, maintained and operated following well proven construction codes, regulations and good practices in operating them. They take due account of siting characteristics, among which weather extremes (e.g. temperature, rainfall, water supply or wind) and other inputs (geology, earthquake, use of land etc…) are fixed based on historical records plus an engineering "safety" margin. New energy infrastructure projects integrate those factors in their feasibility analysis, both from an economic and a safety point of view. Variations in any of the above parameters due to climate change result in the need to perform scheduled revisions of the construction (when project is progressing) or operation specifications, in order to ensure that the operation and integrity of the infrastructure remain within the required safety margins at all time.

To achieve sector- and location specific climate resilience, there is thus a need for a thorough and coherent assessment of local climate impacts – based on historical records, but also including projections on future climatic conditions. Only detailed local assessments can provide greater confidence in understanding current and future climate variability and its impacts on installations. Subsequently, making climate change assessments and system-wide vulnerability checks for interconnected installations, developing long-term (investment) strategies and incorporating climate issues into planning and maintenance procedures can not only ensure the timely adaptation of installations but also avoid future negative externalities.

Climate change affects not only transport infrastructure, but also traffic distribution and traffic flows, which can change infrastructure needs. Since different modes of transport are affected by climate change in different ways, it is possible to change the mobility regime taking into account the vulnerability of the transport sector, as well as the readiness and degree of implementation of adaptation measures. Among the risks for the railway industry in a changing climate are: reduced safety of rolling stock and infrastructure; increased repair and maintenance costs; violation of the delivery time of goods and passengers.

These risks are caused by an increase in precipitation, surface runoff and water content of water bodies. These climate changes may affect the design, construction, and operation of transport infrastructure facilities. Of particular importance is the expected 20% increase in precipitation in the form of heavy rainfall in 2100 [10-12].

Such a dangerous natural phenomenon as flooding is the most common type of natural disaster that has a negative impact on transport infrastructure. In an analysis of disasters recorded in the EM-DAT database from 2000 to 2019, almost half (3254) of all recorded events (7348) were floods (Fig.1).

In areas where watercourses cross railroad tracks under a bridge or tunnel, climate change increases the risk that increased water flows could damage existing or proposed transportation facilities. Thus, one of the measures to adapt transport infrastructure facilities to climate change is to increase by 30% the capacity of the bridge crossing along the flow of water between Copenhagen and Ringsted, compared to current standards [12].

Investments in the construction of buildings and structures that are part of the transport infrastructure require taking into account the changing climate and associated extreme weather events. Also significant is the use of adaptation measures due to the long service life of buildings and structures, economic and social value, taking into account the consequences of climate change.

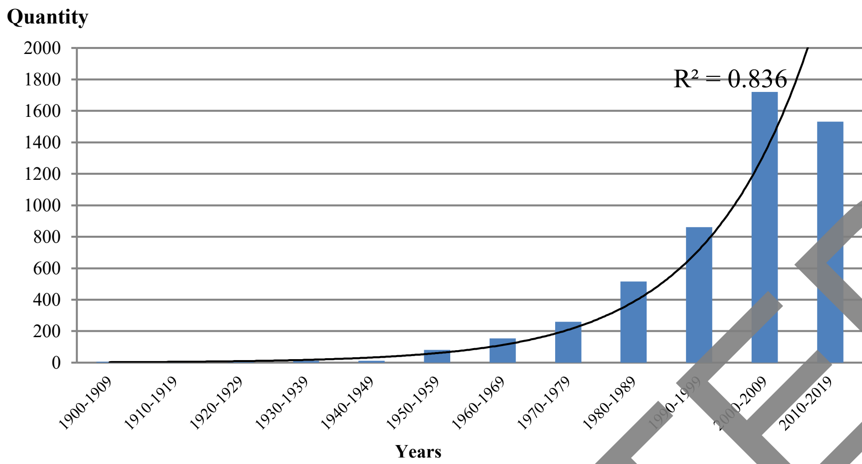

Fig. 1. Change in the number of floods in the world from 1900 to 2019

In addition, adaptation measures for buildings and structures being designed and constructed may differ significantly from existing design and construction practices.

Threats to buildings and structures under design and construction include:

– extreme precipitation leading to flooding of buildings and structures, damage to foundations and bases, destruction of buildings, increased likelihood of landslides, floods, etc.;

– increased snow load on the structures of buildings and structures;

– extremely high temperatures leading to increased fatigue of materials, adversely affecting the health of people in buildings, increased energy consumption for cooling, etc.;

– flooding of territories due to rising water levels in rivers and rising sea levels, which increases the likelihood of soil subsidence and deformation of building structures.

The results of the analysis of the impact of climate risks on the railway infrastructure are presented in the table 1.

Table 1 - Results of analysis of the impact of climate risks on railway infrastructure

Climate factor	Effect of climate factor	Impact on assets
Temperature: change in distribution pattern, higher average and maximum temperature		
High temperatures, heatwaves	overheating	infrastructure
		rolling stock
Quick temperature changes	tension	track buckling
Intensive sunlight	overheating	track buckling, fires, signal problems
Precipitation: change of distribution patterns, more extreme events		
Intensive rain	erosion of soil, landsides, floods	damage to embankments, earthwork
Extended rainy periods	slower drainage, erosion of soil landslides	infrastructure, operations
Flooding: surface water, fluvial		drainage system, tunnels, bridges
Droughts		earthworks
Wind: change of distribution patterns, more extreme events		
Storm (inland)	high winds	damage to installations, catenary
	trees uprooting	disruption of train operation
Coastal storms	coastal flooding	embankments, earthwork, operation
Lightnings	overvoltage	catenary and signaling

Based on the results of the analysis of climate risk factors, the effects of climate risk factors, as well as the impact on railway infrastructure, integrated management of natural hazards and climate change adaptation measures can be based on:

– analysis of information and forecast of adverse weather conditions;
– monitoring and documenting the condition of infrastructure facilities;
– assessment of the resource of infrastructure facilities;
– regional climate forecast and expected climate changes;
– mapping natural hazards and adjusting hazards taking into account climate change forecasts.

Integrated management of natural hazards and the development of measures to adapt to climate change can be based on:
– mapping of transport infrastructure vulnerabilities;
– risk assessment and risk management;
– implementation of adaptation measures at all stages of the life cycle of infrastructure facilities;
– the development of alternative adaptation scenarios, taking into account the costs and assessing the consequences of maladjustment.

Improving measures and strategies for adapting rail transport to a changing climate may include the following systems: a system for reducing the likelihood of accidents and incidents; a system for monitoring environmental parameters and infrastructure facilities based on recording quantitative and qualitative parameters; measures to reduce damage to transport infrastructure facilities; improving production standards; relocation of transport infrastructure facilities if their continued operation in a given area is no longer possible.

The basis for the development and adjustment of a strategy for adapting railway transport to a changing climate can be the identification of priorities for the functioning and development of the industry based on the classification of risks for the industry. Spatial distribution of risks for risk management is possible by mapping risks and vulnerabilities in relation to infrastructure, environment, technological processes and employees [13-16].

Mapping can be based on the development of a geographic information system that includes a database of natural hazards, existing accident prevention systems, the availability of models of natural processes, as well as a database of infrastructure facilities.

4 Discussion

The level of impact of climate risk factors on transport infrastructure facilities will vary significantly depending on the location of the facility, the existing or potential adaptive capacity and sustainability, and the characteristics of regional economic development. This is due to the fact that long-term and medium-term climate forecasts (e.g., temperature increase, changes in the amount and types of precipitation) and the increase in the frequency of extreme weather events have distinct regional specifics.

Climate impacts not only exhibit regional and seasonal patterns (e.g. north/south, winter/summer), but also vary depending on territorial conditions (e.g. urban/rural/coastal area). Therefore, infrastructure adaptation usually requires a comprehensive analysis of various trends and impact patterns on site.

Adaptation of transport infrastructure to a changing climate involves two aspects. First, when designing and building new infrastructure, resilience to climate change can be ensured by designing, siting and operating facilities based on current and projected climate changes. Second, existing infrastructure can be improved to increase its resilience to projected climate parameters by adapting or incorporating into maintenance measures a range of resilience-enhancing activities over the, typically long, life of the facility.

The design thresholds embedded in infrastructure projects can be exceeded in a changing climate. Climate change lead to disruptions that were considered highly unlikely and therefore acceptable. The infrastructure can operate within environmental parameters close to critical, which can be considered as a new norm. The design of infrastructure facilities is carried out in conditions of resistance to past weather conditions, fixed in building codes and operational requirements.

Thus, in order to achieve climate sustainability in the transport industry, depending on the region where the infrastructure is located, it is necessary to assess the impact of the local climate based on recorded extreme weather events, but taking into account forecasts of future climatic conditions.

Spatial planning plays a significant role in the development of transport infrastructure. It should be noted that climate resilience of transport infrastructure is not limited to design decisions and their implementation, but is based on spatial planning, choice of location and necessary compensatory measures. Assessing location options against the backdrop of climate change and developing a set of measures to adapt transport infrastructure facilities are critical.

5 Conclusion

From a territorial point of view, the aspect of adaptation of transport infrastructure is significant, since a significant part of the interconnected infrastructure is concentrated in cities, then the adaptation of the city and transport infrastructure can solve numerous cross-sectoral problems of functioning and development.

Investments in the construction of buildings and structures that are part of the transport infrastructure require consideration of the changing climate and the extreme weather events caused by it. In addition, the development and implementation of adaptation measures is relevant, which is due, as a rule, to the long service life of buildings and structures related to transport infrastructure facilities, their high importance for the economic and social functioning of the region, and the need to consider the consequences of climate change. At the same time, the adaptation measures being developed for both designed and constructed infrastructure facilities may have significant differences from existing approaches to design and construction.

Improving measures and strategies for adapting railway transport to a changing climate may include the following systems: a system for preventing accidents and incidents; monitoring system for environmental parameters and infrastructure facilities; measures to protect railway transport facilities; introducing changes to production standards; relocation of infrastructure facilities when it is impossible to operate them in a given territory.

Priorities for the operation and development of the transport industry, determined on the basis of a comprehensive risk assessment, can be the basis for both the development and adjustment of the strategy for adapting the railway industry to the conditions of a changing climate. Mapping the risks and vulnerabilities of transport infrastructure facilities can make it possible to form a spatial distribution of risks and their ranking, which can be the basis for developing key approaches to climate risk management.

Mapping can be based on the development of a geographic information system that includes a database of natural hazards, existing failure prevention systems, the availability of models of natural processes, as well as a database of infrastructure facilities.

Thus, to achieve climate resilience in the transport industry, depending on the region where infrastructure is located, it is necessary to assess the impact of local climate based on recorded extreme weather events, but taking into account forecasts of future climate conditions.

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