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НАУЧНО-ПРАКТИЧЕСКИЙ РЕЦЕНЗИРУЕМЫЙ СЕТЕВОЙ ЖУРНАЛ

Основная тематическая направленность журнала: материалы о научно-технических, организационных, экономических, экологических, правовых проблемах, истории, состоянии и перспективах развития транспортного комплекса стран БРИКС; о взаимодействии стран БРИКС по вопросам транспортного обеспечения и сотрудничества с другими государствами, мировыми транспортными системами, а также о подготовке персонала всех уровней для транспортной отрасли и развитии в данной сфере сотрудничества образовательных учреждений и транспортных предприятий разных стран.

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Prospects for further development of logistics and trade in Central Asian Countries

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ABSTRACT This paper examines the conditions of foreign trade of the Central Asian countries and their impact on economic growth. Currently, the transport corridors of Central Asia are at the peak of their demand. The current positive changes and achievements of the region are considered. Attention is drawn to the geopolitical trends that create conditions for the development of alternative transport corridors and infrastructure projects. Special attention is paid to improving transport connectivity. It is proposed to develop transit and transport potential and increase the production of finished products. The comprehensive analysis carried out in this work allows us to take a broader look at the potential of the region and propose measures for its full development. Due to the growing role of Central Asia in the international arena, this paper also examines the impact of foreign policy on the development of the region's economy. The strategic location of Central Asia between China, Russia, Iran and other countries makes the region an important partner in international trade and transport links. The paper analyses the current positive developments in the region, such as the creation of new transport corridors, the development of logistics infrastructure and the strengthening of trade relations with other countries. Special attention is paid to projects for the development of regional integration and economic unions, which contribute to improving competitiveness and economic stability in Central Asia.

KEYWORDS: transport; investments; logistics; railway; infrastructure; trade; market; transport corridor

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Научная статья

Перспективы дальнейшего развития логистики и торговли в странах Центральной Азии

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АННОТАЦИЯ Рассматриваются условия внешней торговли стран Центральной Азии и их влияние на экономический рост. В настоящее время транспортные коридоры Центральной Азии находятся на пике своей востребованности. Исследуются текущие позитивные изменения и достижения региона. Обращается внимание на геополитические тенденции, которые создают условия для развития альтернативных транспортных коридоров и инфраструктурных проектов. Особое внимание уделяется повышению транспортной связности.

Предлагается развивать транзитно-транспортный потенциал и увеличивать производство готовой продукции. Проведенный всесторонний анализ позволяет шире взглянуть на потенциал региона и предложить меры для его полноценного развития. В связи с растущей ролью Центральной Азии на международной арене также рассматривается влияние внешней политики на развитие экономики региона. Стратегическое расположение Центральной Азии между Китаем, Россией, Ираном и другими странами делает регион важным партнером в международной торговле и транспортных связях.

Проводится анализ текущих положительных изменений в регионе, таких как создание новых транспортных коридоров, развитие логистической инфраструктуры и укрепление торговых отношений с другими странами. Особое внимание уделяется проектам по развитию региональных интеграционных и экономических союзов, которые способствуют повышению конкурентоспособности и экономической стабильности в Центральной Азии.

КЛЮЧЕВЫЕ СЛОВА: транспорт; инвестиции; логистика; железная дорога; инфраструктура; торговля; рынок; транспортный коридор

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INTRODUCTION

Looking at Central Asia, it can be said that it is a large and dynamic region with a promising development trend. The geographical location and resource wealth of the sub-region make it an important “theatre” for a major political play [1]. However, the world still has not fully realized the economic role and prospects of Central Asia.

The countries of Central Asia are currently actively improving in the context of global digitalization, which involves the development of regional infrastructures. In this connection, it can be suggested that the development of transport and logistics will be one of the main areas of transport policies in these countries. Central Asian countries are believed to be some of the least connected economies in the world. The region’s connectivity indicator averages below 60 % of global GDP, which is the lowest on this scale. The cost of imports and exports in Central Asia remains high, undermining the competitiveness of domestic goods abroad and increasing the cost of imported goods for local consumers. For example, the cost of shipping a container from any country in Central Asia to Shanghai is more than five times the cost of shipping it from Poland or Turkey.

Transport connectivity within the countries of Central Asia is also limited. Thus, the majority of parts of the region have no necessary transport infrastructure and the cost of shipping services is high. This limits access to services, economic activities, and employment and hampers the development of tourism.

COUNTRIES OF CENTRAL ASIA: PROBLEMS, ACHIEVEMENTS, DEVELOPMENT PROSPECTS

Countries of the region have made significant progress in their development over the last 20 years and have good prospects for growth. However, due to inertia, the international community still does not see the region as a significant player on the global economic map. At the same time, Central Asia is growing rapidly and has a significant potential. The creation of a favourable (institutional, industry-based, socio-economic and macroeconomic) environment in the economies of Central Asia will form a basis for their sustainable growth.

The region’s GDP has on average grown 6.2 % annually in real terms over the last 20 years to reach USD 347 billion [2]. The population of Central Asia is almost 80 million people and continues to grow by 2 % per year. The amount of accumulated investments from third countries is USD 211 billion and foreign trade turnover has increased sixfold since 2000.

The region’s railway sector is currently facing the following systemic problems:

- shortage of capacity in the railway infrastructure and locomotive traction;
- obsolescent technologies and standards;
- lag in the development of central hubs;
- shortage of human resources;
- weak bargaining positions in interactions with foreign railway administrations.

The problem with land gives rise to numerous interrelated complications [3, 4]. The question of how to solve this problem has been discussed many times in various working groups. Stabilizing the situation in the transport sector is currently a pressing issue.

Achievements and structural change in Central Asia over the last 20 years show positive dynamics in the following dimensions:

- the total population has grown to reach 80 million people, with the vast majority being accounted for by Uzbekistan (35 million people);
- GDP grew 7.5 times to reach USD 347 billion;
- foreign trade of goods increased 6 times to reach USD 165.5 billion;
- on average, the population numbers in the region increased by 1.6 % per year.

This shows clearly that performance in trade and business is improving. It should be noted that over the last 20 years the economies in Central Asia have grown at a significant average annual rate of 6.2 %. By contrast, the same figure for the world as a whole is 2.6 %, and for developing countries it is 5.3 %.

The aggregate GDP of five countries of Central Asia is moving closer to being comparable with the economy of China in terms of significance. All this has positive effects on trade between the countries, boosting the growth of trade. As a result, the foreign trade turnover increased six times, despite that not all of the issues have yet been resolved.

Sustainable development and economic growth will require that the four major structural challenges be overcome:

- the need for the development of the transit and transport potential to establish a Eurasian transport system;
- reduction of barriers to the inflow of private investment, increasing the output of finished goods, and diversification of exports;
- well-coordinated development of the water and energy sectors;
- transition to a green economy.

At the same time, geopolitical trends provide opportunities for the growth of alternative transport corridors and infrastructure projects.

Russia and China are the key trade partners of Central Asian countries. Geographically, Central Asian countries are at the intersection of the major transport corridors, which gives them an opportunity to develop their transport potential, primarily for the transportation of goods, and for the involvement of Central Asian countries in cross-border production chains [5].

Today, the transport corridors in Central Asia are in peak demand. Strategies of Central Asian countries build on leveraging globalization and regional economic integration.

Thus, China, Kyrgyzstan and Uzbekistan are considering building an alternative route with access to the Caspian Sea.

Russia is building the North – South route. This year, the flow of export goods from Russia along this corridor increased by about 10 million tons [6].

Tajikistan has launched a multimodal corridor China – Tajikistan – Uzbekistan – Turkmenistan – Iran – Turkey. The cargo will be delivered from the People's Republic of China to Kulyab, Tajikistan, which is a Tajik free economic zone and will become a commercial, transit and industrial hub in the republic [7].

Iran is intending to reconstruct the Herat – Khaf railway section to develop trade with Herat, one of the most prosperous cities in Afghanistan. This project is also aimed at the creation of a transport corridor to Middle Eastern countries, and to India, Europe and Southeast Asia through the Iranian port of Chabahar. What is special about the Khaf – Herat railway is that it can considerably reduce transport costs, simplify the customs procedures for international transport, and facilitate transit of goods and development of commercial and economic relations. Once completed, the project will enable the transportation of 6 million tons of goods and 1 million passengers per year [8].

At present, the countries of Central Asia experience positive changes. 2022 saw the relocation of major global brands and recruitment of highly skilled specialists. A share of foreign investment has notably increased, indicating higher interest in the region. Diversification of exports is expanding both in terms of the product profile and the countries of destination. It should be noted that the share of imports of finished goods and products from Central Asia has also increased. These changes suggest that the region is developing and expanding its trading relations across the globe.

The region is experiencing investment growth. Countries of Central Asia are successful in attracting foreign investment. The list of international organization is very extensive, with all of them having permanent establishments in the region. An important role in concessional financing is played by programs of international organizations, such as the World Bank, the World Monetary Fund, the Asian Development Bank, the Islamic Development Bank, etc. At the same time, Russia and China remain the leaders in the region, mainly targeting its resource sector [9].

In 2023–2030, private investment will apparently focus on:

- construction of terminals;
- purchase of rolling stock;
- introduction of new technology, further digitalization of freight and passenger transportation;
- development of transport and logistics businesses;
- construction of dry cargo ships and ferryboats.

The investment interest levels still vary between the countries of Central Asia. Kazakhstan is best positioned among the countries of the region, ranking 25th among 190 countries of the world in the Doing Business 2020 rating. Uzbekistan is also strengthening its positions, ranking 69th. Kyrgyzstan and Tajikistan rank 80th and 106th, respectively [10, 11].

Having established the freedom of trade and economic relations, Uzbekistan is a good model of successful reforms in the national economy for other countries in Central Asia. The region's countries can use its experience in liberalization of the economy to stimulate the development of their industrial, agricultural and foreign trade sectors, and improve the business environment.

Today, the population of Earth is 8 billion people and it continues to rapidly grow. Based on this, it is natural that consumer demand is constantly growing. At the same time, global change takes place in logistics. Changes are driven by events, such as the drought in Europe, China and the United States; the flood in Pakistan; fires in Brazil and Kazakhstan; the war in Ukraine and sanctions against Russia; significant increases in consumer prices; military escalation around Taiwan; food hunger for 1.3 billion people on the planet; a leap in delivery rates; changes in traditional logistics; the earthquakes in Turkey and Syria.

In connection with the above factors, some international experts predict a global crisis, inflation and budget shortfalls.

Land resources have always been essential for the social and economic development of society. Therefore, the nature and scope of reforms in the land sector are considered as one of the factors to determine the growth rate and performance in the development of a national economy and establishment of market relations.

Another important factor for the development of countries in Central Asia is exports of raw material. There is a prospect for increasing exports to South Asia, primarily of oil and gas. Goods traffic between countries of Central Asia and South Asia can be expanded, in particular by extending the range of imported goods, first of all, equipment and consumer goods.

The lack of direct transport routes to South Asian countries restrains the development of trade, regardless of short distances. The development of the North — South international transport corridor via Afghanistan to Pakistan and Iran will help resolve this restraint, enabling goods from Central Asian countries to enter, among other things, the international market using the infrastructure of seaports in the Persian Gulf.

The majority of scholars currently become aware of a huge potential of digitalization, arguing that robotics and automation are the key technologies to promote modernization and sustainable development of the agricultural and processing industries [12].

Despite the ambitious plans for the development of logistics infrastructures in countries of Central Asia, their transport corridors still have bottlenecks, such as:

- varying levels of development of transport systems;
- lack of synchronization and proper coordination;
- shortage and lag in the development of infrastructure;
- complex procedures for accessing direct investment funds;
- lack of rolling stock (locomotives and railcars);
- lack of state-of-the-art technology, weak or varying levels of digitalization.

All this poses a risk of unbalanced development of transport and logistics.

It should be also noted that the problems accumulated in the railway sector directly impact trade. These problems affect all railway administrations in the CIS.

CONCLUSION

Central Asia is located at the intersection of the key land transport arteries. Historically, it has been a bridge between East and West, North and South, and currently it represents the backbone of the Eurasian transport system. Therefore, it is important to make joint efforts with countries of Central Asia to coordinate development.

Sustainable development and economic growth will require that the four major structural challenges be overcome:

- the need for the development of the transit and transport potential in order to establish a Eurasian transport system;
- reduction of barriers to the inflow of private investment, increasing the output of finished goods, and diversification of exports;
- well-coordinated development of the water and energy sectors;
- transition to a green economy.

Integration processes should be active. Besides, the region should optimize its intangible infrastructure simultaneously with the development of national transport infrastructures in order to harmonize regulation of the transport sector and simplify border crossing procedures.

By solving the region's structural problems, you will be able to unlock its economic potential to a full extent. Increasing transport connectivity will stimulate mutual trade, industrial cooperation, and activity of businesses along the transport corridors, thus ensuring that the region is open to trade.

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Forecasting material flows of modern logistics centres of railway freight stations exemplified by Xi'an (the People's Republic of China)

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ABSTRACT The purpose of the study is to create a more accurate material flow forecasting model of Xi'an freight railway station in China. The combined forecasting model is more validated for forecasting freight flows of regional logistics compared to three methods: grey forecasting, Markov chains, entropy weighting. Through the creation of the combined model, the grey forecasting method is combined with Markov chain correction, and the projected data is compared with the actual data to obtain higher accuracy of the forecasting model.

A combined model using the grey forecasting method combined with Markov chain correction is created, with the forecast data compared with the actual data to obtain high accuracy of the forecasting model.

The practical significance is that in the context of the present post-pandemic economic development, the logistics enterprises that do not operate in accordance with the modern logistics methods may be displaced by competitors. If the railway does not improve its logistics infrastructure, logistics equipment, railway logistics network platform, etc., it will lose out to other modes of transport. In order to meet the needs of logistics and improve the market competitiveness, the main indicator of a freight station is loading and logistics flow. Therefore, exact prediction of future changes in the logistics flow of a freight station can help to determine whether the station needs to be upgraded as a railway station or transformed into a certain type of a logistics centre.

KEYWORDS: rail freight; regional logistics; grey forecasting; GM (1,1) grey model; Markov chain; combined forecasting

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Научная статья

Прогнозирование материальных потоков современных логистических центров железнодорожных грузовых станций на примере Сианя (Китайская Народная Республика)

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АННОТАЦИЯ Цель исследования — создание более точной модели прогнозирования материальных потоков грузовой железнодорожной станции Сиань в Китае.

Комбинированная модель прогнозирования является более обоснованной в прогнозировании грузопотоков региональной логистики по сравнению с тремя методами: серого прогнозирования, цепей Маркова, взвешивания энтропии. Благодаря созданию комбинированной модели метод прогнозирования серого сочетается с коррекцией цепи Маркова, а прогнозируемые данные сравниваются с фактическими данными, чтобы получить более высокую точность модели прогнозирования.

Создана комбинированная модель с использованием метода прогнозирования серого в сочетании с коррекцией цепей Маркова, при этом прогнозируемые данные сравниваются с фактическими данными для получения высокой точности модели прогнозирования. Практическая значимость — в условиях современного постпандемийного экономического развития логистические предприятия, которые не работают в соответствии с современными методами логистики, могут быть вытеснены конкурентами.

Если железная дорога не усовершенствует логистическую инфраструктуру, логистическое оборудование, платформу железнодорожной логистической сети и т.д., она проиграет конкурентную борьбу другим видам транспорта. Для удовлетворения потребностей логистики и, таким образом, повышения рыночной конкурентоспособности, основным показателем грузовой станции является погрузка и логистический поток. Поэтому точное прогнозирование будущих изменений в логистическом потоке грузовой станции может позволить определению, нуждается ли станция в модернизации, как железнодорожная станция, или преобразовании в определенный тип логистического центра.

КЛЮЧЕВЫЕ СЛОВА: железнодорожные перевозки; региональная логистика; серое прогнозирование; серая модель GM (1,1); цепь Маркова; комбинированный прогноз

Для цитирования: *Ван Хэлинь, Коровяковский Е.К.* Прогнозирование материальных потоков современных логистических центров железнодорожных грузовых станций на примере Сианя (Китайская Народная Республика) // Транспорт БРИКС. 2024. Т. 3. Вып. 3. Ст. 2. https://doi.org/10.46684/2024.3.2.

INTRODUCTION

With the continuous process of increasing the complexity of forecasting models and improving algorithm technology, the accuracy of forecasting various economic indicators has also undergone great changes. Most forecasting methods are currently based on the input data to create a forecasting model with high accuracy according to time series, and the maximum goodness of fit can be achieved by repeated use of the model, which ensures the accuracy of forecasting results. Logistics flow forecasting is mainly organised chronologically based on the actual logistics flow over a period of time to establish a mathematical model that fits the actual distribution law of the random variable. The single modelling approach has limitations for certain situations, while the creation and use of the model also has certain limitations; therefore, to improve the accuracy of the forecast, it is necessary to compensate for the shortcomings of the single model by creating highly specialised models.

Forecasting of transport and logistics indicators and an attempt to prove the prospectivity and validity of applying artificial neural networks (ANN) compared to other forecasting methods are presented in [1, 2]. Forecasting freight traffic in the traditional way is exponential smoothing, least squares analysis, time series and other methods. However, obtaining reliable forecasting results, even for short-term periods, is quite complicated for such difficult to forecast and dynamically changing indicators as the volume of transportations of production, trade, transit or other cargoes, because flows are heterogeneous in time and space; therefore, this requires their easily accessible validation which can be carried out indirectly by several methods of comparison of forecasting results [3, 4]. Even in this case, direct validation may be only considered to be comparison of formulated forecasts combined with actual data which are only obtained at the end of the preparation period [4, 5]. Therefore, the decision was made to use two methods for forecasting, one of them being the exponential smoothing method, and the other being the grey forecasting method with Markov chain correction not so often used for traffic volumes forecasting.

PROBLEM OF TRANSFORMATION OF RAILWAY FREIGHT STATIONS

Definition of a railway logistics centre

A railway logistics centre is usually an element of a transport hub of a large agglomeration, has full information support, carries out logistics activities for the economy and society and performs such functions as providing logistics services, has sufficient storage capacity, throughput and processing capacity [6].

Analysis of the issues of transforming freight railway stations into modern logistics centres

At present, the number of railway freight stations in China is huge, and the scope, location and main functions of freight stations are not uniform. If the transformation and modernisation is carried out without a prior comprehensive analysis, it will be both impossible to develop modern logistics and may lead to waste of resources. Based on the analysis of some information sources and relevant literature on freight stations and railway logistics centres and with account of the key factors, it is outlined that the railway freight station turns into a modern logistics centre that adapts to various functional services.

The railway freight station is an important railway network junction. This junction has a certain coverage. Therefore, this attribute should be used as one of the elements of transformation analysis [7]. The factors under study are large volume of commercial operations, large freight flows and large-scale industrial parks, presence of large industrial units within the radius, with the decision on the possibility of transformation made based on the analysis of these factors.

Geographical features

Railway freight stations and railway transport lines form the railway transport network. The development of railway freight hubs and the development of regional cities go together. However, when they develop in an uncoordinated manner, freight stations become a significant obstacle to urban development. Due to the scarcity of land resources, freight stations may also be relocated to urban fringes in the urban development process.

At present, the central freight yards in many cities are gradually reducing their freight business and shifting their main business to urban fringes [8]. Therefore, when selecting a freight station for transformation, it is necessary to consider the geographical position of the existing freight station, and for modernisation, a freight station with expansion and construction capabilities should be selected, so that the newly built railway logistics park should further promote the development of urban economy. This both promotes the expansion of the city size and facilitates the development of the railway logistics centre.

Scale conditions

A modern railway logistics centre should have complete logistics equipment in terms of scale, and can provide basic logistics services, such as co-storage, handling, distribution; therefore, the choice of transformation usually involves selection of a freight yard with a relatively large freight handling volume [9]. At the same time, other auxiliary transport functions of the freight yard should also be relatively complete, while its area, existing scale and operating yard should meet certain conditions, and the freight yard should have a certain reserved space [10].

Problems of station allocation and coordination in large agglomerations

Given the current development of modern logistics, there still are various ungrounded problems in its planning. Take Xi'an railway junction as an example. This area has 16 freight stations with large annual traffic volume. The decentralised structure of small freight stations does not allow for economies of scale, and it is difficult to change to meet the market requirements (*Fig. 1*).

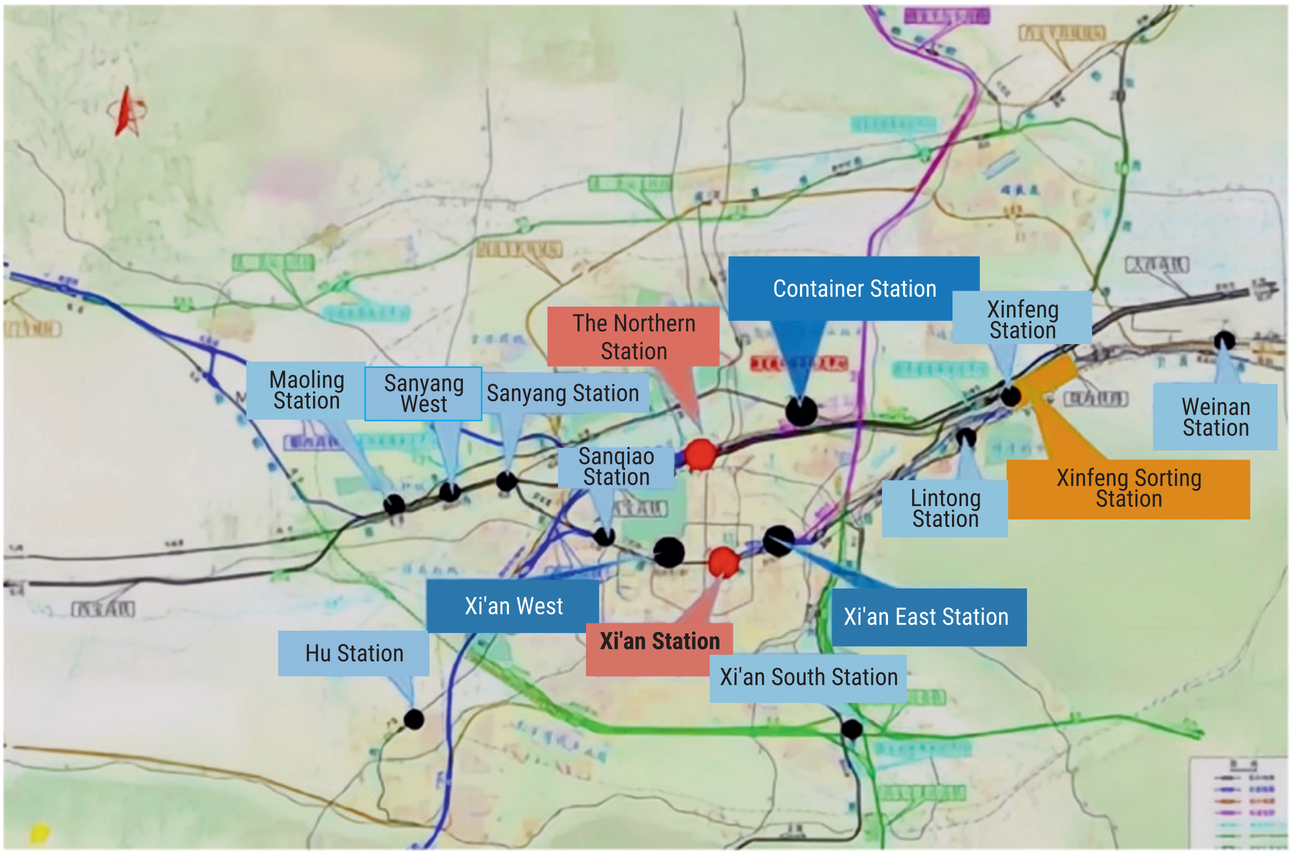

Fig. 1. Distribution scheme of freight railway stations in Xi'an agglomeration area (URL: https://shidian.baike.com/wikiid/86385658282055880?anchor=2)

Fig. 2. Xi'an East Railway Station (URL: https://m.thepaper.cn/baijiahao_20513940)

The development of Dongcheng high-speed railway area relies on the Xi'an East Station Transport Hub, which is connected to the core area in east Xi'an, but also enhances the business development in central Xi'an through industrial upgrading, space renovation, infrastructure improvement and environmental improvement. *Fig. 2* shows the design of Xi'an East Station Hub.

Xi'an East Railway Station will become a large-scale integrated transport hub combining high-speed railway, conventional railway, intercity transport, underground and public transport. Once its reconstruction is completed and put into operation, the annual passenger traffic is expected to reach 36.5 million people. This will improve the urban transport capacity and directly contribute to the economic development of eastern Xi'an.

FORECASTING TECHNOLOGY FOR TRANSFORMING RAILWAY FREIGHT YARDS INTO MODERN LOGISTICS CENTRES

Transformation of railway freight yards into modern logistics centres has become a key task for the development of modern logistics in the railway transport industry. The necessity and feasibility of modernisation were analysed previously, and an important factor driving the conversion is the change in freight volumes and modernisation of transport functions; therefore, it is necessary to forecast the volumes of freight handled at terminals [11].

A grey combination forecasting method based on Markov chain correction with entropy is proposed, with the accuracy of the forecasting method verified by comparing the relevant data.

Overview of forecasting methods

The key forecasting methods include the field method, market research method and brainstorming method; quantitative forecasting is mainly based on the correlation of things and time and is divided into causal forecasting and time series forecasting due to the many correlations affecting the development of events and the difficulty of determining the correlations, with the time series being the main parameter in forecasting [12].

The freight flow is a combination of several data, which mainly includes the superposition of transportation, storage and distribution demand data. But in practice, there is still no clear definition of the freight flow; so in this paper, we will define the freight flow as a simple superposition of freight volume, storage, distribution and processing, due to the transformation and upgrading of railway freight yards into modern logistics centres The function expansion is also mainly focused on increasing the warehouse function and distribution function, and the loading and unloading volume is a key indicator of the location of the facilities and equipment in the fleet; therefore, it is easy to determine, which provides accurate data to make effective forecasts [13].

Study of material flow forecasting technology model

Model overview

It follows from the basic composition of material flow that if a single forecasting model is used for forecasting, its own shortcomings and application limitations will increase, which will affect the accuracy of forecasting results, and the meaning of forecasting will be lost; therefore, the combined model of GM (1,1) and Pierre F. Verhulst is introduced. To integrate the model, use is made of the entropy weighting method to ensure the effective integration of the combined model, and a Markov chain is introduced to adjust the obtained values of the forecasting model, so that the forecasting results are transformed from single data into material flow intervals, and the probability of interval formation is effectively estimated, which improves the reliability of forecasting [1].

GM (1,1) model building process

The model is built for training and adjustment of the existing data series to find a mathematical function with some kind of law according to certain criteria to improve the degree of "whiteness", so as to bring the forecasting effect to the expected results. The model is usually a first-order multivariate model. Especially widely usd is the GM (1,1) model wih the following forecasting stages:

1. Based on the initial values, the following values are determined

$$x^{(1)}(t) = (x^{(1)}(1), x^{(1)}(2), ..., x^{(1)}(n)) \text{ i.e.}$$

$$x^{(1)}(t) = \sum_{k=1}^{t} x^{(0)}(k), \quad t = 1, 2, ..., n. \tag{1}$$

2. The matrix B and the constant vector Y_n are constructed

$$B = \begin{pmatrix} -0.5\left(x^{(1)}(1) + x^{(1)}(2)\right),1 \\ -0.5\left(x^{(1)}(2) + x^{(1)}(3)\right),1 \\ \ldots \\ -0.5\left(x^{(1)}(n-1) + x^{(1)}(n)\right),1 \end{pmatrix};$$

$$Y_n = (x^{(0)}(2), x^{(0)}(3), ..., x^{(0)}(n))^T. \tag{2}$$

3. The following is solved for grey parameters using the least squares method

$$\left(\frac{a}{u}\right) = (B^TB)^{-1}(B^TY_n). \tag{3}$$

4. Substitution of elements of the grey parameter vector into the time function

$$x^{(1)}(t+1) = \left(x^{(0)}(1) - \frac{u}{a}\right)^{e^{-at}} + \frac{u}{a}. \tag{4}$$

5. $x^{(1)}(t)$ is differentiated to obtain

$$x^{(0)}(t+1) = -a\left(x^{(0)}(1) - \frac{u}{a}\right)e^{-at}. \tag{5}$$

6. $e^{(0)}(t)$ balance is calculated and relative error $q(x)$ is calculated.

7. Verification of errors, the verification criteria are
A. $q(x) \le 0.01$, accuracy for class 1;
B. $q(x) \le 0.05$, accuracy for class 2;
C. $q(x) \le 0.10$, accuracy for class 3;
D. $q(x) \le 0.20$, accuracy for class 4.

8. Using the model for forecasting and results.

Building a Pierre Verhulst model

Let $x^{(0)}$ is initial data sequence; $x^{(t)}$ is single accumulation $x^{(0)}$ to generate the sequence 1-AGO

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2), ..., x^{(0)}(k), ..., x^{(0)}(n)); \tag{6}$$

$$x^{(1)} = (x^{(1)}(1), x^{(1)}(2), ..., x^{(1)}(k), ..., x^{(1)}(n)), \tag{7}$$

where $x^{(1)}(k) = \sum_{k=1}^{k} x^{(0)}(i)$, $k = 1, 2, 3, ..., n$; $Z^{(1)}$ is average generating sequence $X^{(1)}$ in close proximity, i.e.

$$Z^{(1)} = (Z^{(1)}(1), Z^{(1)}(2), ... Z^{(1)}(k), ..., Z^{(1)}(n)), \tag{8}$$

where $Z^{(1)}(1) = X^{(1)}(1)$

$$Z^{(1)}(k) = \frac{1}{2}x^{(1)}(k) + x^{(1)}(k-1), \quad k = 2, 3, ..., n.$$

Then formula

$$X^{(0)}(k) + az^{(1)}(k) = b(z^{(1)}(k))\delta \tag{9}$$

is said to be a model of GM (1,1, a) order.

Then we transform equation 9 into the form of a differential equation

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b(x^{(1)})^{\alpha}. \tag{10}$$

Let's call this the whitening equation for the "GM (1,1 a) order" model.

Solution of the equation

$$x^{(1)}(t) = \left(e^{-(1-a)at}(1-a)\int be^{(1-a)at}dt + c\right)^{\frac{1}{1-a}}. \tag{11}$$

When a = 2, the formula is called the Pierre Verhulst model:

$$x^{(0)}(k) + az^{(1)}(k) = b(z^{(1)}(k))^2. \tag{12}$$

This formula is the differential equation of the Pierre Verhulst model:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b(x^{(1)})^2. \tag{13}$$

Let's solve the differential equation 13 to get:

$$x^{(1)}(t) = \frac{ax^{(1)}(1)}{bx^{(1)}(1) - \left(a - bx^{(1)}(1)\right)e^{at}}. \tag{14}$$

Thus, the forecasting model of the discrete Pierre Verhulst model has the following form:

$$x^{(\hat{1})}(k+1) = \frac{ax^{(1)}(1)}{bx^{(1)}(1) - \left(a - bx^{(1)}(1)\right)e^{ak}}. \tag{15}$$

EXAMPLE OF A MATERIAL FLOW FORECASTING STUDY

Example and process

To check the validity and reliability of the model, the freight flow of Xi'an freight railway station from 2008 to 2019 was selected as an example for the empirical study *(Table 1)*.

Table 1

Xi'an's cargo turnover in 2008–2019

Years	Actual cargo turnover, thousand tonnes	Symbols in the mathematical model
2008	11,250	$x^{(0)}(1)$
2009	12,300	$x^{(0)}(2)$
2010	14,030	$x^{(0)}(3)$
2011	15,660	$x^{(0)}(4)$
2012	18,450	$x^{(0)}(5)$
2013	20,380	$x^{(0)}(6)$
2014	21,780	$x^{(0)}(7)$
2015	23,530	$x^{(0)}(8)$
2016	23,830	$x^{(0)}(9)$
2017	25,230	$x^{(0)}(10)$
2018	26,720	$x^{(0)}(11)$
2019	31,230	$x^{(0)}(12)$

GM (1.1) grey model forecast formula of Xi'an freight railway station flow from 2008 to 2019.

$$x^{(\text{i})}(t+1) = 1.54839.2756e^{0.0801t} - 14315.276. \quad (16)$$

Pierre Verhulst's forecasting formula:

$$x^{(1)}(t+1) = \frac{-104.3281}{-0.0024 - 0.0891e^{-0.08984t}}. \quad (17)$$

Let's calculate the forecast value of the freight station logistics flow according to the forecasting formula and compare the results. The results are shown in *Table 2*, where the formula for calculating the error is as follows

$$\varepsilon_1 = \frac{\left(x_1 - \widehat{x_{ij}}\right)100}{x_1}, \quad i = 1, 2, ..., m; \;\; t = 1, 2, ..., n. \; (17)$$

Combined forecasting models

Suppose that the initial sequence of data is $x = (x_1, x_2, ..., x_n)^T$, the forecast value of the ith single forecasting model at time t is equal to $\widehat{x_{it}} = (i = 1, 2, ..., m;$ $t = 1, 2, ..., m)$, the vector consisting of weight coefficients of each individual model has the following form $\omega = (\omega_1, \omega_2, ..., \omega_n)$, the resulting grey combination forecasting model is

$$\widehat{y_t} = f\left(\widehat{x_{it}}, \omega_i\right), \quad i = 1, 2, ..., m; \;\; t = 1, 2, ..., n. \quad (18)$$

Determining the model weights for each combined forecasting model

Establishing effective model weights for each particular forecasting model is a key step in ensuring the accuracy of the combined forecasting results [1]. In this study, the weights for each particular forecasting model are determined based on the information entropy theory and the degree of variation of relative errors of different models.

1) Let the relative error of the ith forecasting method at time t be

$$e_{it} = \begin{cases} 1, & \left(x_t - \widehat{x_{it}}\right)/x_t \geq 1 \\ \left(x_t - \widehat{x_{it}}\right)/x_t, & 0 \leq \left(x_t - \widehat{x_{it}}\right)/x_t \leq 1 \end{cases}. \quad (18)$$

Table 2

Comparison of forecast results for 2009–2019

Years	Forecast data / 10,000 tonnes		Actual cargo turnover / 10,000 tonnes	Error limit ε_1, %	
	GM (1,1)	Pierre Verhulst		GM (1,1)	Pierre Verhulst
2009	1414.5	1330.84	1230	–12.5294	–0.0668
2010	1498.07	1346.31	1403	–6.8903	3.9730
2011	1625.57	1472.30	1566	–3.6118	5.9841
2012	1756.79	1609.67	1845	4.7210	13.339
2013	1903.30	1810.21	2038	7.0023	13.9524
2014	2109.50	2002.46	2178	5.5562	10.3456
2015	2345.82	2137.97	2353	6.1573	9.4236
2016	2414.27	2293.07	2383	–1.3119	3.7443
2017	2613.98	2503.96	2523	–3.6468	0.7555
2018	2830.10	2730.93	2672	–5.9204	–2.2056
2019	3064.32	2978.34	3123	1.8793	4.6325

2) Normalization of errors

$$f_{it} = e_{it} / \sum_{t=1}^{n} e_{it}, \quad i = 1, 2, ..., m; \quad t = 1, 2, ..., n. \quad (19)$$

3) Calculation of entropy values for the ith forecasting method

$$H_i = -1/Inn \sum_{t=1}^{n} f_{it} Inf_{it}, \quad i = 1, 2, ..., m; \quad t = 1, 2, ..., n. \quad (20)$$

It follows that for the ith model, if f_{it} are equal, i.e. $f_{it} = 1/n$, $t = 1, 2, ..., n$. Then H_i takes on big value 1, and we have $0 \le H_i \le 1$.

4) Let's calculate the coefficient of variation for the ith forecasting method:

$$V_i = 1 - H_i, \quad i = 1, 2, ..., m. \quad (21)$$

5) Let's determine the weight coefficient for the ith forecasting method

$$\omega_i = \frac{1}{m-1}\left(1 - V_i \,/ \sum_{i=1}^{m} v_i\right), \quad i = 1, 2, ..., m. \quad (22)$$

6) Let's build a combined forecasting model

$$\widehat{y_t} = \sum_{i=1}^{m} \omega_i \widehat{x_{it}}, \quad t = 1, 2, ..., n. \quad (23)$$

According to the forecast results in *Table 2*, in conjunction with the relevant entropy method principle, the correlation weight coefficient of each forecasting model is calibrated, the vector of weight coefficients calculated by the formula (3.1)–(3.10), is:

$$\omega = (0{,}6731, 0.3269).$$

Thus, the corresponding model of the combination of entropy methods is obtained as follows

$$\widehat{y_t} = \left(0.6731\widehat{x_{1t}} + 0.3269\widehat{x_{2t}}\right). \quad (24)$$

The forecast compliance value obtained using the combined forecasting model is written as $\widehat{y_t}$.

COMPARISON OF ACCURACY OF THE RESULTS

Let's define the forecasting accuracy indicator as the average relative error of the forecasted values in order to compare the accuracy of forecasting models. Formula for calculating the average relative forecast error

$$\Delta_i = \frac{1}{n}\sum_{t=1}^{n} \frac{|x_t - x_{it}|}{x_t} 100, \quad i = 1, 2, ..., m. \quad (25)$$

Let's enter the accumulated data into the formula and the calculation results are shown in *Table 3* and *Fig. 3*.

Table 3

Average relative error of different models

Forecasting models	GM (1,1)	Pierre Verhulst	Combined forecast models
Relative error, %	6.4266	5.2416	4.0653GM

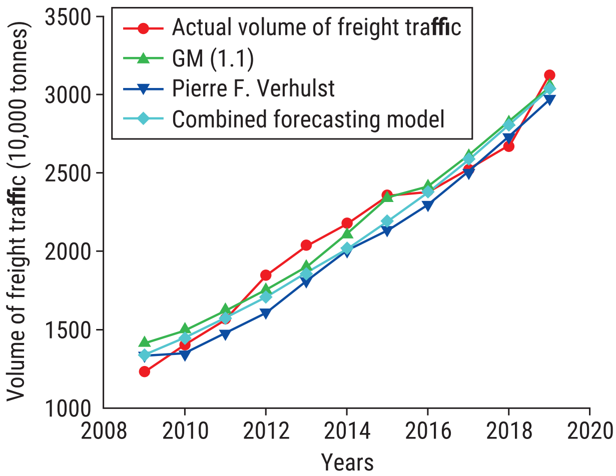

Fig. 3. Graph of forecast results for different forecasting methods

CORRECTION OF MODEL FORECAST RESULTS

Markov chain correction forecast results

The forecast result of the grey combination model is a single value; this forecast result will give a certain error with respect to the actual value. To ensure the accuracy of the forecast result we use Markov chain methods to accurately combine the forecast values into a small range of intervals, on this basis we calculate both the probability [14, 15] and the probabilistic problem of its interval generation.

The central aspect of the Markov chain approach is to determine a probabilistic approximation of the number of transitions m_i from sample state S_i into state S_j as m_{ij}, i.e.

$$P_{ij} = m_{ij}/m_i, \quad (26)$$

where P_{ij} is the probability of transition of Markov chain state S_i to state S_j.

The properties of P_{ij} value are:

$$0 \le P_i \le 1; \quad \sum_{j=1}^{n} P_{ij} = 1. \quad (27)$$

The state transition matrix is built in the form

$$P = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_n \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{pmatrix}. \quad (28)$$

According to the method, the results of the combined forecast are categorised into three states when compared with the actual freight volume values: First, the residuals as a percentage of the actual freight volume less than –15 % and greater than –5 % are overestimated states (E1); the forecast residuals from –5 % to 5 % of the actual freight flows are normal (E2); the forecast residuals as a proportion of the actual freight flows in the range from 5 to 15 are called underestimated states (E3). Based on this classification criterion, the occurrence of each state in the combined forecast scenario is shown in *Table 4*.

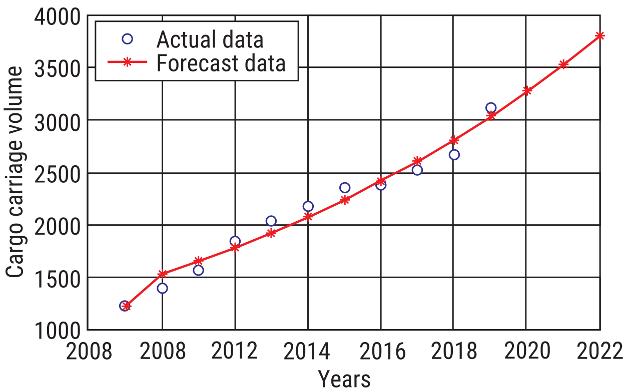

Fig. 4. Optimised graph of forecast data of freight traffic volume

Table 4

The forecast value and classification status of the combined forecasting model from 2009 to 2019

Years	Combined forecasting model / 10,000 tonnes	Actual cargo turnover / 10,000 tonnes	Error limit ε_1, %	State
2009	1336.48	1230	−8.6571	E1
2010	1451.28	1403	−3.5150	E2
2011	1575.87	1566	−0.6303	E2
2012	1711.07	1845	7.2088	E3
2013	1857.76	2038	8.8438	E3
2014	2016.88	2178	7.3974	E3
2015	2189.47	2353	6.9501	E3
2016	2376.60	2383	0.2684	E2
2017	2579.48	2523	−2.2790	E2
2018	2799.36	2672	−4.7660	E2
2019	3037.60	3123	2.7348	E2

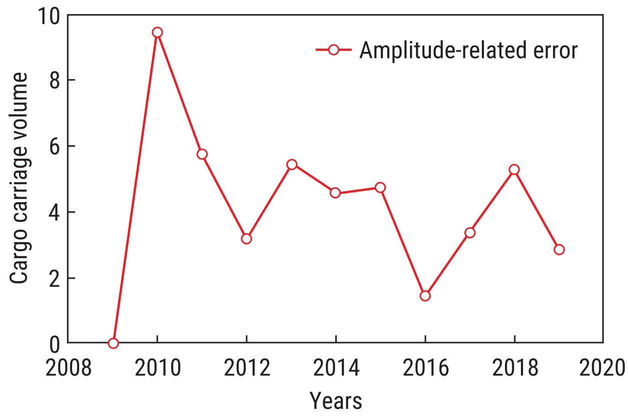

Fig. 5. Relative error in forecasting the freight traffic volume

Table 5

Forecasting results after Markov chain correction

Years	Combined forecast results	Forecasting results after Markov chain improvement		
		Status space	Probability	Range of forecast values
2020	3357.16	E1	0.0000	[239.05, 3024.35)
		E2	0.8000	[3024.35, 3423.68)
		E3	0.2000	[3423.68, 3642.68)
2021	3572.09	E1	0.0000	[3125.28, 3403.56)
		E2	0.6900	[3403.56, 3870.65)
		E3	0.3100	[3870.65, 4234.90)
2022	3874.21	E1	0.0000	[3312.07, 3700.49)
		E2	0.6295	[3700.49, 4086.92)
		E3	0.3705	[4086.92, 4395.34)

Based on the Markov correction principle, the algorithm of the combined forecasting model on MATLAB can be improved to increase the accuracy of the forecasting results, as well as the subsequent output of the forecast state vectors, as shown in *Figs. 4*, *5* and *Table 5*.

Comparing the forecast data for 2020 and 2021 in *Table 5* with the actual traffic volume data of Xi'an Station, we can conclude that the results forecast by the model better reflect the development trend of the future traffic volume and can more accurately forecast the future traffic volume, and the model itself is more efficient.

CONCLUSION

Most existing methods for forecasting regional flows require the collection of a multitude of diverse data affecting flows. The variety of statistical methods leads to complex causal analyses, making the data difficult to use. Using the combined forecasting model and Markov chain to improve and adjust the forecasting results, the traffic volume of Xi'an railway station and the development of Xi'an's logistics demand were forecasted, and the probability situation of the occurrence of the corresponding intervals of logistics demand for the forecast year was obtained. Logistics flow forecasting plays an important role in the development of macro-logistics initiatives of the government. Based on the statistical data of Xi'an city freight turnover of Shaanxi Province from 2008 to 2019, the freight flows for 2020–2022 are forecasted, and the combined forecasting model is more validated for forecasting the logistics scale of the region compared to the GM model (1.1).

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Selection of railway track superstructure design: Modern outlooks

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ABSTRACT The paper analyses the reasons for the current opinion that a higher mass of superstructure elements is necessary for railway track sections with higher traffic density, speed and axial loads. With the help of known theories and the new one developed by the author that takes into account the time factor, it is proved that in terms of all the most significant technical indicators the best solution within the realistic limits is to use lower-mass rails and reinforced concrete sleepers. The most essential argument in favour of the smaller mass of rails per unit length is the increased track stability produced by longitudinal compressive forces in rails. A reinforced concrete sleeper of a smaller mass has been proposed and tested that increases the resistance to shear in ballast across the track axis at least two times. For stable pressing of rails to sleepers by intermediate fasteners, elastic clips should be made of plate steel instead of bar steel. It is proposed to make a plate clip shaped as a 'fish-bellied beam'. Specific examples of the proposed solutions for rails, reinforced concrete sleepers, and intermediate fastenings are given.

KEYWORDS: construction of superstructure elements; mass of superstructure elements; rails; reinforced concrete sleepers; intermediate fastenings; elastic clips; methods for the design of superstructure elements; strength; stability

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Научная статья

Выбор конструкции верхнего строения железнодорожного пути: современные представления

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АННОТАЦИЯ Анализируются причины бытующего мнения о необходимой более высокой массы элементов верхнего строения для участков железнодорожного пути с повышенными грузонапряженностью, скоростью и осевыми нагрузками. С помощью известных теорий и вновь разработанной автором, учитывающей фактор времени, доказывается, что по всем наиболее существенным техническим показателям лучшими в реальных пределах являются меньшая масса рельсов и железобетонных шпал. Значимым аргументом в пользу меньшей погонной массы рельсов служит повышение устойчивости колеи при действии в рельсах продольных сжимающих сил. Предложена, изготовлена и испытана железобетонная шпала меньшей массы, создающая при этом не менее чем в два раза повышенные сопротивления сдвигу в балласте поперек оси пути. Для стабильного прижатия рельсов к шпалам промежуточными скреплениями упругие клеммы должны быть выполнены не из прутковой, а из пластинчатой стали. Пластинчатую клемму предлагается изготовить в виде «балки равного сопротивления». Приводятся конкретные примеры предлагаемых решений по рельсам, железобетонным шпалам, промежуточным скреплениям.

КЛЮЧЕВЫЕ СЛОВА: конструкция элементов верхнего строения пути; масса элементов верхнего строения пути; рельсы; железобетонные шпалы; промежуточные скрепления; упругие клеммы; методы расчетов элементов верхнего строения; прочность; устойчивость

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INTRODUCTION

There is a notion that due to higher train velocity, traffic density and axial load levels that are typical of modern rail transport, the track superstructure should be built of heavier rails and larger reinforced concrete sleepers and, if this is not enough, also have a reinforced concrete ballastless under-rail base (a slab).

This opinion is based on works of Professor Georgy M. Shakhunyants [1–3] and the dependencies of mass of a rail per unit length on train velocity, traffic density, and axial load. These were derived fairly long ago by the approximation of trends in global engineering policies in the subject area in the mid-20th century. In his paper [1], the author presents the dependencies with a reservation that these should only be used *"as preliminary and tentative guide values"*. However, his progeny often used the formulas $Q(T, P, V)$ [3], where Q is mass per unit length; T is traffic density; P is axial load; and V is velocity, as if they were deterministic functions.

The publication [1] contained the following formulas [3]

$$Q \geq a(1 + (T_{\max} / \lambda_p)^{1/4}[(1 + 0.012V)P]^{2/3}_{\max}, \quad (1)$$

where $a \approx 1.20$ for railcars and $a = 1.13$ for locomotives; λ_p is the rail quality factor which ranges from 1.5 to 2.0 for hardened rails.

The research [4] conducted by the authors on operating railway sections has shown that within the realistic limits, the relationship in $Q(T, P, V)$ dependencies is not direct but rather almost inverse. In essence, this paradox means that Georgy M. Shakhunyants determined the approximate dependencies $Q(T, P, V)$ [1] at the time when the USSR had no continuous welded rail track and therefore he did not take into account the longitudinal thermal forces occurring in rails. Longitudinal thermal forces that occur in rails in a continuous welded rail track can cause deflections that may compromise the safety of train traffic (*Fig. 1*).

Fig. 1. Typical view of a bucked track section

Experts in the subject field are well aware that longitudinal thermal forces in rails are directly related to the cross-sectional area of rails, which is a negative factor. But the larger the cross-sectional area, the greater the bending stiffness of rail, which was seen as a positive factor. In this case, they usually referred to the fact that the dimension of cross-sectional area is m^2, while the second moment of area used in the formulas is in the dimension of m^4. This was mistakenly regarded as if stiffness dominated area and hence preference should be given to rails with a higher mass per unit length.

However, if we look at particular formulas that are used for determining the conditions for stability of continuous welded rail track by known methods, then under the static conditions where no impact from trains is taken into account, these formulas will be as follows [5]

$$F = 4(EIq/f)^{1/2} \text{ with } f = ql^4/415EI, \quad (2)$$

and where the impact from trains is taken into account by applying creep theory methods and hence the time factor is incorporated as well, the formulas will look as follows [6]

$$f = f_0 \exp(F^2\tau/16EI\xi) \text{ with } f = ql^4/415EI, \quad (3)$$

where f and f_0 are current and original bends of rails in the horizontal plane, respectively, with stressed irregularity along the bending length l, m; F is longitudinal compressive thermal force in rails, $F = \alpha E\omega(\Delta t)$, kN; τ is time, s; E is modulus of elasticity of rail steel, MPa; I is equivalent moment of inertia in a track panel when bent in a horizontal plane, m^4; ξ is an empirical factor of viscous resistance of ballast per unit length for displacement of sleepers transverse to the track axis, $N \cdot s/m^2$; $\xi = r/\dot{\lambda}$; $\dot{\lambda} = d\lambda/d\tau$ is velocity at which sleepers move in the ballast, m/s; q is resistance of ballast per unit length to displacement of sleepers transverse to the track axis, kN/m.

For the purposes of a comparative assessment of the influence of mass of a rail per unit length on the conditions for stability of continuous welded rail track, we can use the first of the expressions (2) to determine the value of resistance per unit length q required for maintaining the stability of continuous welded rail track, depending on rail cross-sectional area ω and rail second moment of area I: $q = A(\omega^2/I)$. The same dependence is obtained from the first expression (3) if we determine the value of viscous resistance per unit length ξ necessary for maintaining the stability of continuous welded rail track depending on rail cross-sectional area ω and rail second moment of area I: $\xi = B(\omega^2/I)$.

A and B are the factors that incorporate all the other similar mechanical characteristics of the variants compared. The calculation shows that with a 10 kg increase in the mass of a rail per unit length, the resistance per unit length q and resistance per unit length ξ that are required to maintain the stability of continuous welded rail track should be approximately 15 % higher. The calculations assume the actual, most unfavourable states of a track with the minimal rail pressing force on the sleeper in intermediate rail fastenings and the same rail bottom width of 150 mm within the range of the rail mass per unit length of 55 to 75 kg/m. A 15 % increase in the required resistance per unit length q or ξ with an increase of the rail mass per unit length by 10 kg is a huge value that should not be neglected. Since q and ξ values are random with a large dispersion and they are difficult to control in field, values to be taken into account in calculations should be as low as possible. It should be noted that the second expressions (2) and (3) show that an in-plan stressed irregularity in rails of higher mass is less steep, which should not be regarded as their benefit.

RAILWAY TRACK SUPERSTRUCTURE

According to the existing standards, track measuring means must, first of all, detect stressed irregularities as the most dangerous ones. In rails of higher mass, an in-plan irregularity with the same slope may be stressed and hence is dangerous for traffic. For rails of lower mass, the same irregularity will be stress-free, i.e. not dangerous.

In Europe and Japan, rails with a mass per unit length of above 60 kg/m are not in use and these countries have no problems with providing stability for continuous welded rail tracks. In the United States, only rails with a higher mass per unit length are in use and they have problems with the provision of stability, but the United Sates have almost no passenger rail traffic.

At present, almost all rails no the major railway lines in Russia are R65 rails. For nearly forty years, new rails of other types have not been used in overhauls. Currently, it is proposed to produce R71 and R75 rails. The proposal is mainly based on the assumption that there is the dependence (1), or, more specifically, that in rails of greater mass, edge stresses, when calculated by the method currently in use, are reduced and vertical loads on the under-rail base from the rolling stock are distributed more evenly. At the same time, it was mistakenly assumed [7] that this would also provide higher stability of continuous welded rail track.

As for stability, the above evidence should make it clear that stability significantly decreases with an increase in mass of rails per unit length. When the actual conditions are taken into account, i.e. vertical subsidence of track, edge stresses in rails do not decrease but increase instead [8]. Although even for the most unfavourable conditions of interfacing between the track and rolling stock, the realistic values of edge stresses are far from the probable minimum values of elastic limit of rail steel (800 MPa) [9]. Edge contact stresses depend on the service life of rails. The higher the bending stiffness of rails, the greater contact stresses [10]. Based on calculations by the method currently in use, a 10 kg increase in the mass of rails per unit length produces an insignificant, about 6 %, reduction in vertical loads on the under-rail base. Vertical loads cause deflections in the under-rail base to grow, while the quality of design and the condition of the under-rail base have influence on the growth rate of subsidence at least an order of magnitude higher than mass of rails per unit length. Besides, vertical subsidence is less dangerous for movement of trains than horizontal in-plan irregularities produced by longitudinal compressive thermal forces.

Given that consequences of derailment due to impaired stability of continuous welded rail track are highly severe, especially for passenger trains, a requirement was introduced in the framework of Russia's current regulations[1] that rail strings should be fastened at a relatively high temperature. Depending on a climate profile, this temperature should be at least plus 25–30 °C. The expressions (2) and (3) show that stability conditions depend on longitudinal force F^2. In order to securely provide for the stability of continuous welded rail track, regulations should set even higher temperature levels for fastening rail strings. But this would increase tensile longitudinal thermal forces in rails that act at temperatures below the rail fastening temperatures for a longer period within a year than compressive forces. In absolute terms, the maximum possible tensile forces can be about two or three times as high as compressive forces depending on the climate zone. In cold months, tensile thermal forces make the gaps at the ends of rail strings open to the maximum, placing track bolts in shear, which should not be allowed according to traffic safety specifications.

The current standards[1] mistakenly suppose that end sections of rail strings are no more than 60 meters in length. In this case, the joint gaps at the ends of rail strings would not have opened to the extent that track bolts would be in shear. This is only possible when resistances per unit length to longitudinal displacements, as pointed out in[1], are 12 kN/m on a single rail length. In fact, the majority of researchers in the field have found by way of experiment that resistances per unit length to longitudinal displacement were much

[1] Инструкция по устройству, укладке, содержанию и ремонту бесстыкового пути (утверждена распоряжением ОАО «РЖД» 14.12.2016 № 2544р).

lower. For example, according to data of the Railway Research Institute (VNIIZhT) [11], their maximum values are 2.6 times as little as the average values given in1. But all engineering calculations should take into account the actual, most unfavourable conditions. The value of longitudinal displacement of the end of a rail string l at a single long-term decrease in the temperature of rails from the fastening temperature under the static conditions without taking into account the impact from trains is determined using the following formula [11]

$$\lambda = \alpha^2 E\omega(\Delta t)^2/2r, \quad (4)$$

and when the impact from trains is taken into account it is determined as follows [6]

$$\lambda = \alpha(\Delta t)(\pi E\omega t/K)^{1/2}, \quad (5)$$

where r is resistance per unit length of ballast displaced by sleepers along the track axis; K is an empirical factor of viscous resistance per unit length of ballast displaced by sleepers along the track axis, $N \cdot s/m^2$.

Calculations using both the formula (4) and formula (5) have shown that with actual values of r and K, displacements of rail string ends are considerably greater than the allowable gap, thus placing track bolts in shear. The larger the cross-sectional area of the rail ω, the greater the calculated values of λ (3) and (4).

In order to prevent shear failure of bolts or where shear failure has already occurred, during the cold season, maintenance personnel have to replace the rails adjacent to the ends of rail strings with expanded ones at the ends of rail strings of a continuous welded rail track. According to some unofficial data, these account for about 20 % of the total number of joints. However, this does not mean that the remaining 80 % of joint track bolts were in shear and it was just a good fortune that no shear failure occurred. Before being sheared, track bolts can accept some longitudinal tensile force; therefore shear failure of bolts is not found in every joint.

In this connection, extra-long rail strings with welded joints should be used not only within an entire railway haul, but also welded to turnouts that also have their joints welded. Any bolted joints produced by temporary repair should be removed by welding to restore the prescribed operating temperature of rail strings at such sections within a period of at least two months.

Based on the above, we propose to produce an R58 rail that will be optimal for any operating conditions in all respects, especially in terms of traffic safety.

It is believed that in order to increase the resistance per unit length to horizontal shear of reinforced concrete sleepers in crushed stone ballast, it is necessary to increase their mass. This opinion is based on the findings of experiments conducted without taking into account the impact from trains. Indeed, in accordance with Coulomb's law, under the static conditions, a greater mass of a sleeper should produce a greater resistance to its shear in ballast. However, the tests carried out on operating sections [12] have shown that horizontal longitudinal and transverse forces transmitted from the rails make sleepers with an increased mass move at least as fast as standard ones.

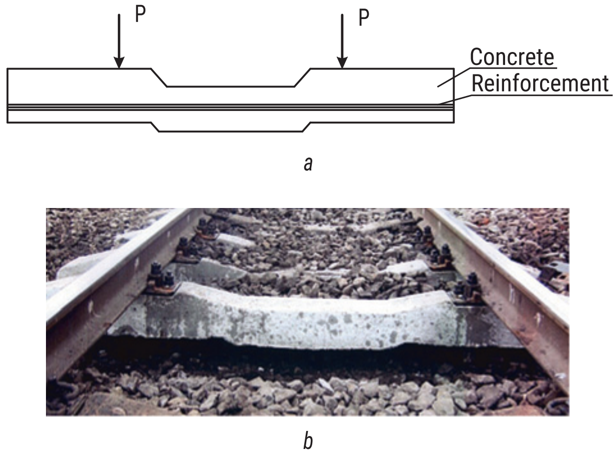

Fig. 2. Proposed reinforced concrete sleeper: *a* — diagram of changing the location of concrete mass and pre-stressed reinforcement; *b* — view of a sleeper laid in the track

A reinforced concrete sleeper with a mass reduced by 45 kg [13] has been proposed, fabricated and tested by a standard method both in a factory lab and on an operating track. Shear resistance in ballast transverse to the track axis it produces is at least twice as much as that of a standard one. This effect is achieved by changing the configuration of the sleeper on its supporting surface, by creating a small protrusion in the middle of it. *Fig. 2, a* shows a diagram showing the changed location of the concrete mass and pre-stressed reinforcement, and *Fig. 2, b* shows a pilot batch of the proposed sleepers manufactured based on the standard technology and laid on an operating track section.

In line with the bending moment diagram, the protrusion brings the pre-stressed reinforcement closer to the tensile region, thereby both reducing its mass, while maintaining the required strength of the sleeper, and increasing the shear resistance in ballast transverse to the track axis at least two times.

The selection of a reasonable design for intermediate fastenings is essential. All the resilient rail fastening designs currently used in Russia (ZhBR, ARS, Pandrol, Vossloh) use elastic clips made of bar steel. Bars are good for torsion loads, but they cannot be strong in bending, while it has not been possible to remove bar clips in bending in any of the known designs. As a result, when bar clips are used, the rail pressing force on the sleeper quickly goes down to zero due to plastic de-

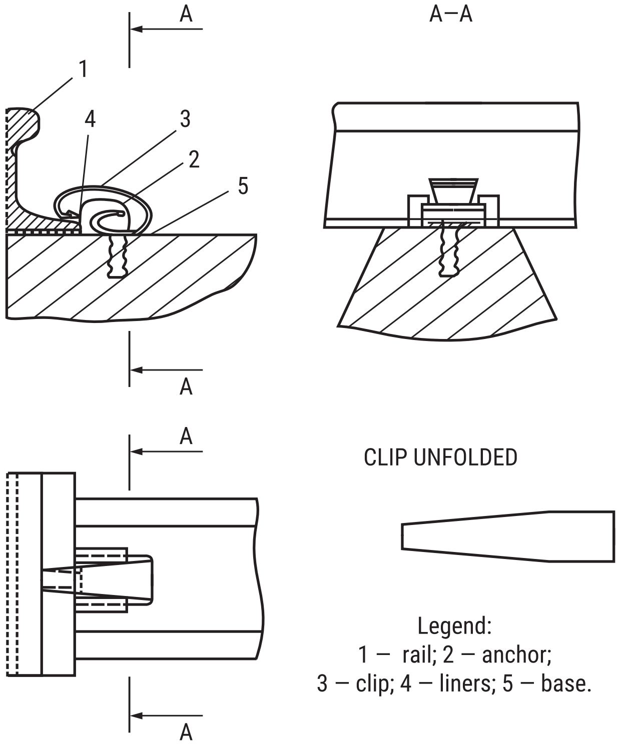

Fig. 3. Proposed boltless elastic rail fastening

formations during operation subject to traffic intensity. Then rail creeping begins.

For a clip to be strong in bending, it should be made from plate steel.

It is proposed to use a low-part fastening that is sufficiently elastic and allows for adjusting the rail position for height (within 20 mm) without sleeper tamping. A plate clip is shaped as a "fish-bellied beam" with a configuration that allows for imbedding it into the anchor [14]. This fastening is shown on *Fig. 3*.

The fastening has only one part. It is a clip inserted into an anchor embedded in a sleeper when the latter is manufactured. Unlike, for instance, ARS fastenings, this clip can be easily mounted and removed using a fairly simple mechanism. The clip is shaped as a "fish-bellied beam"; it is vandal proof thanks to a fairly high mount compression force in the anchor and has the optimal rail pressing force on the sleeper (*Fig. 3*).

Sometimes, it is proposed to use a reinforced concrete slab as an under-rail base. This increases the cost of laying the track which may then never pay off if it turns out that expenses are not expected for the current maintenance. Approximately 50 years ago in the USSR, several designs of reinforced concrete under-rail bases were tested but had to be abandoned due to the fact that with the then current maintenance, problems caused by deflections in the base were almost insoluble.

CONCLUSION

In any real-life situations, it is cheaper, easier and more reliable to use a track panel set on crushed stone ballast. At the same time, it is better to use R58 rails, the proposed lightweight reinforced concrete sleepers, and boltless elastic rail fastenings with plate clips shaped as a "fish-bellied beam".

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Prospects of autonomous railway transport development

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ABSTRACT The implementation of unmanned train control systems offers a number of advantages, such as increasing the capacity of railway lines and traffic volumes, reducing the 'human factor', as well as reducing operating costs. The paper considers the challenges arising from the use of automatic train control systems, and presents the prospects for the implementation of automatic technologies in railway transport for various railway systems. The social and economic aspects of changing professional activities in railway transport are described. Grades of automation applicable to surface urban railway transport are presented. The issues of proving the functional safety of machine vision systems as part of the train traffic control system and determining their level of safety completeness are discussed. Examples of railway transport automation in Russia and other countries are given. Basic scenarios of automatic control system operation describing normal and abnormal situations are formulated. In conclusion, the levels of technological readiness of the reviewed solutions in the field of train traffic automation are defined. The tasks faced by railway companies in implementing these technologies are outlined, and possible ways of overcoming obstacles to the introduction of automatic systems are proposed, taking into account the current political situation.

KEYWORDS: autonomous transport; grades of automation; automatic train control system; machine vision; artificial intelligence (AI); machine learning; datasets; functional safety; safety integrity level (SIL)

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Научная статья

Перспективы развития беспилотного железнодорожного транспорта

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АННОТАЦИЯ Внедрение систем беспилотного управления поездами предоставляет ряд преимуществ, таких как повышение пропускной способности железнодорожных линий и объемов перевозок, снижение «человеческого фактора», а также сокращение эксплуатационных затрат. В статье рассмотрены вызовы, возникающие при использовании систем автоматического упраавления движением поездов, представлены перспективы реализации автоматических технологий на железнодорожном транспорте для различных железнодорожных систем. Описаны социоэкономические аспекты изменения профессиональной деятельности в сфере железнодорожного транспорта. Представлены уровни автоматизации, применимые к наземному городскому железнодорожному транспорту. Рассмотрены вопросы доказательства функциональной безопасности системы технического зрения в составе системы управления движением поездов и определения их уровня полноты безопасности. Приведены примеры автоматизации железнодорожного транспорта в России и странах мира. Сформулированы базовые сценарии работы системы автоматического управления, описывающие штатные и нештатные ситуации. В заключении определены уровни технологической готовности рассмотренных решений в области автоматизации движения поездов. Указаны задачи, стоящие перед железнодорожными компаниями при реализации таких технологий, а также предложены возможные способы преодоления препятствий на пути внедрения автоматических систем с учетом текущей политической обстановки.

КЛЮЧЕВЫЕ СЛОВА: беспилотный транспорт; уровни автоматизации; система управления движением поездов; система технического зрения; искусственный интеллект (ИИ); машинное обучение; датасеты; функциональная безопасность; уровень полноты безопасности (SIL)

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INTRODUCTION

The rapid development of digital technologies, such as artificial intelligence, computer vision, and broadband radio communications, is contributing to the active introduction of elements of unmanned control systems in railway transport. The interest in these systems is motivated not only by the general trend towards digitalisation, but also by social and economic factors related to the growth of urban agglomerations and the changing structure of the professional orientation of society, resulting in a reduction in the number of qualified personnel available on the market in a number of basic railway industry occupations, including train driver.

In many countries of the world, including the BRICS countries, railway companies are already feeling the effects of labour market changes in the form of a shortage of qualified basic engineering staff, and this trend is likely to increase. The transfer of most of the monotonous routine vehicle driving tasks to automatic control systems may be a part of the solution to this problem. The advantage of an automatic control system is not only a reduction in the number of personnel, but also an increase in throughput — a reduction in the interval between trains. In addition, there is a trend of increasing remuneration costs and reducing the cost and labour intensity of developing train automation systems. A good example of such a situation is the cost of a lidar (a laser scanner): over the last five or six years, its price has fallen more than ten times, while the technical characteristics have increased by two to three times.

GRADES OF AUTOMATION OF TRAIN MOVEMENT CONTROL

The IEC 26690:2014 standard describes general requirements for an automatic control system for surface urban railway transport. In 2022, the Research Institute of Informatisation, Automation and Communications in Railway Transport (NIIAS JSC) developed a Russian analogue — the national standard GOST 70059[1], which describes the following grades of automation (GoAs) (*Fig. 1*):

GoA0: Fully manual control of the rolling stock. At this grade of automation, the driver performs all train control activities without the need for additional systems to control the train. Permissions to proceed, slow orders, and route determinations can be given by means of wayside signals, permanent railway traffic rules, or by personal or radioed verbal instructions.

GoA1: Manual control of the rolling stock. At this grade of automation, the driver in the locomotive cab monitors track vacancy and wayside signal aspects, controls the traction and braking systems, as well as the opening and closure of the doors. His actions are monitored by an on-board safety device installed on the train, which prevents him from exceeding the speed limit and passing a stop signal aspect.

GoA2: Semi-automatic train control, where the driver is responsible for activating the system, switching it to an ATO (automatic train operation) mode, checking for obstructions on the track, opening/closing doors and taking action in the event of abnormal situations. Traction and braking control, as well as supervision of compliance with speed limits, are done automatically.

GoA3: Train control without a driver. At this grade of automation, the driver is not in the train cab. All functions related to train control are performed by the automatic system. Since the driver is unable to monitor the vacancy of track sections, the occurrence of obstacles in the course of the train movement must either be unlikely enough to eliminate the need for a person in the cab, or be detected by additional technical means for monitoring the track. Automatic control of rolling stock without a driver requires the presence of a conductor on board. His or her duties may include ensuring the safe departure of the train from the platform, closing the doors, assisting passengers, and taking necessary actions in emergency situations.

[1] GOST R 70059-2022.

Grade of automation	Train operation	Setting train in motion	Driving and stopping the train	Door closure	Operation in event of disruption
GoA1	ATP with Driver	Driver	Driver	Driver	Driver
GoA2	ATP and ATO with Driver	Driver/ Automatic	Automatic	Driver	Driver
GoA3	Driverless	Automatic	Automatic	Attendant/ Automatic	Attendant
GoA4	Unattended	Automatic	Automatic	Automatic	Automatic

Fig. 1. Grades of automation of operating modes in railway transport

GoA4: Fully automatic rolling stock control. Fully automatic operation corresponds to the highest grade of automation 4. The train is controlled in a fully automatic mode without any personnel on board, so additional safety measures are required. Personnel are usually only involved during maintenance or in the event of abnormal events, e.g. a fire on the train. In this scenario, actions to neutralise abnormal situations are carried out with the participation of a driver-operator, dispatchers, and a rapid response team.

In terms of passenger safety, even at the fourth grade of automation, an automatic control system does not pose any additional threats to people inside an electric train. Automatic blocking systems and on-board safety devices, which have the maximum safety level and have been in use for many years, protect against collisions with other rolling stock.

Numerous comparative tests of obstacle detection systems using human dummies show that the developed machine vision system (ODS — an obstacle detection system) outperforms human drivers in terms of detection range and reaction time. This will reduce the likelihood of non-work related injuries in the future.

At the same time, the issue of selecting a methodology for proving the functional safety of the ODS as part of an on-board train control system (OTCS), including the determination of the safety integrity level (SIL) for such a system, is still open and requires additional research. It is obvious that the use of an artificial neural network (ANN), whose behaviour cannot be fully described or predicted, does not allow us to categorise an ODS as a system with a high level of functional safety SIL4.

Many experts propose to divide the OTCS into a safety part (safety kernel) represented by a locomotive safety device operating in a protected control loop, and a machine vision system that operates in a separate control loop (see *Fig. 2*) [1].

Functional safety refers to the ability of a safety related system to fulfil all of its designed safety functions under all specified conditions for a specified period of time while maintaining the residual risk of hazardous events at an acceptable level. Safety completeness is the level of satisfactory fulfilment by a safety-related system of the required safety functions under all specified conditions for a specified period of time. The higher the level of safety completeness of systems, the lower the probability of failure of these systems when they fulfil the required safety functions. In determining safety completeness, all causes of failures leading to an unsafe condition should be considered, e.g. hardware failures, failures caused by software, hardware failures, or operator errors.

Safety integrity level 1 (SIL1) is the lowest, but it requires the use of good development expertise. It can be achieved relatively easily if the requirements of quality standards are applied throughout the system development and production phases. IEC 61508-12 and other documents categorise SIL1 as 'non-safety related'.

The second level (SIL2) is not much more difficult to achieve than the previous one, but it requires a greater number of inspections and tests. This level requires that there is a good design and application practices correspond to the level required by ISO 9001. As a result, the cost of the system increases.

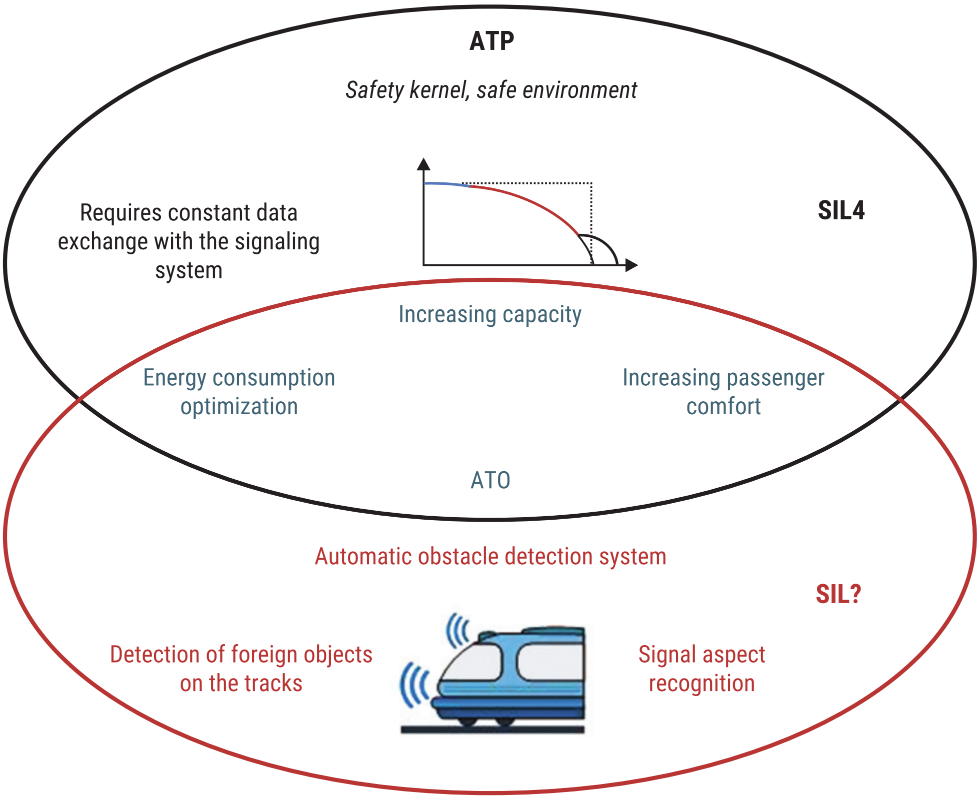

Fig. 2. Schematic diagram of a modern OTCS with intelligent control

Achieving Safety Integrity Level 3 (SIL3) requires greater effort and higher developer competence than for SIL1 and SIL2, along with the use of multi-channel hardware and multi-version software. The system cost and development time are important factors. In this case, the choice of implementers becomes limited, as few of them are able to provide this level.

Level 4 (SIL4) requires the most rigorous development, including the application of formal methods. The cost of the project will be extremely high and the system will require an extremely high level of expertise. In some cases, it is possible to avoid the use of SIL4 by adding more protection levels.

A dangerous failure is a rare event, and determining its probabilistic parameters by experimental methods will take much longer than the lifetime of the device under study. Mathematical modelling of the processes of occurrence of dangerous failures allows for accelerating the investigation of devices and control systems for compliance with safety requirements. To implement the modelling requires an appropriate mathematical description of the object of study — the process of occurrence of dangerous failures, which cannot be fully implemented in relation to a system that includes an ANN. When creating complex multilevel OTCS, it is necessary to develop a comprehensive approach to the rational use of analytical and experimental ways and methods of safety proof by combining heterogeneous information to obtain reliable estimations of proof of functional safety of such systems. For this purpose, it is advisable to combine the results of mathematical modelling with accelerated in-situ tests, results of expert examination of technical and design documentation, tests of simulation models of software and hardware, bench tests, and safety assessments based on statistical data on failures in use [2].

Functional safety requirements are preliminarily checked by developers for their realisability taking into account the available resources of a particular project and, if necessary, adjusted in terms of composition and values taking into account the risks. At the same time, an additional element performing the function of control and limitation can be introduced into the OTCS with the use of automatic obstacle detection. A remote driver-operator is most often considered as such an element for making decisions in case of data inconsistency in control loops, but other fully automatic variants are also being studied.

As an example, let us take the scheme of the OTCS implemented on the Moscow Central Circle (MCC). The MCC OTCS is implemented as a multi-loop control system with two control modes: 'autonomous' and remote (remote-controlled operation). In *Fig. 3*, the red dotted line highlights the subsystems that make up the safety loop of the GoA3/4 mode [3].

In addition to the traditional system of automatic train signalling based on coded track circuits, the MCC OTCS features radio-channel interaction between sta-

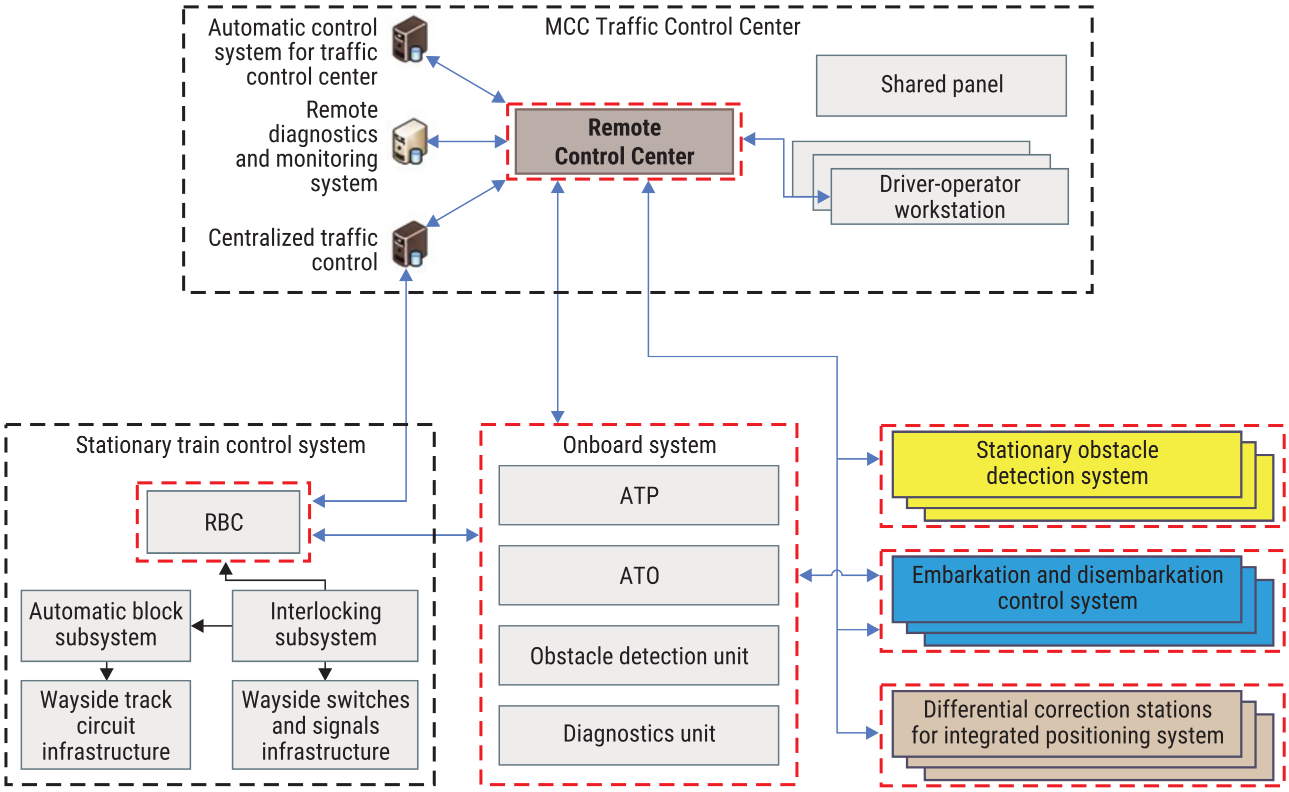

Fig. 3. General design of the MCC OTCS

tionary and on-board train traffic control systems, while a separate circuit solves the tasks of automatic obstacle detection by on-board and stationary visual inspection devices using artificial neural networks and transmitting relevant information to the Remote Monitoring and Control Centre.

REMOTE DRIVER'S ROLE

Automatic train control systems are designed so that if there is an obstacle on the railway track, such as a fallen tree, the train will automatically stop. Further actions after the train has stopped are already the responsibility of a human driver, who will decide whether it is necessary to dispatch a rapid response team or whether it is possible to proceed in remote control mode if the obstacle does not endanger the movement of the rolling stock.

The profession of a driver-operator is relatively new, but the development of digital technology and the increase in traffic volumes are opening wide prospects for it. Among the tasks of such a specialist are remote control of electric trains and remote control of a train in the event of an abnormal situation. The driver-operator must be able to process a large amount of information and take prompt action to resolve the situation. His workstation reflects data on the condition of trains and infrastructure, passenger boarding and disembarkation processes, and the occurrence of irregularities and deviations in the operation of systems of an electric train[2].

It is natural to consider the question of designing a workplace for such a specialist. The Locomotive Engineering Design Bureau of Russian Railways JSC, in cooperation with NIIAS JSC, is developing a driver-operator workplace included in the integrated technology of unmanned electric train traffic on the Moscow Central Circle [4]. It is assumed that in the future driver-operators will remotely control several trains on the railway network. And if now the tested technology and algorithm capabilities provide for one driver-operator for four trains, in the future, the number of trains under the control of a single driver-operator can be significantly increased. The task of monitoring a large amount of information involves a larger field of view, so the images from cameras of electric trains are displayed on a 49" widescreen monitor. The controls must be within arms' reach and be positioned identically to those in the cab of an operating electric train. Some controls, such as for changing the lighting or heating in the cab, will no longer be necessary, so the functionality of the driver's workstation should also be reviewed. It is also necessary to provide for the

[2] Driver-operator / RZD Digital. URL: https://rzddigital.ru/career/professions/mashinist-operator-/

possibility of quick switching between controlled electric trains. When developing the remote control and control panel for unmanned electric trains, the functional duties of the driver-operator and the experience of current driver-instructors who take part in the testing and generation of ergonomic requirements for the workplace are taken as a basis.

UNMANNED TRAIN OPERATING SCENARIOS

Analysing the actions of employees and the functioning of systems in regular and abnormal situations also provides the basis for defining scenarios for the operation of the automatic control system. Since the organisation of unmanned train traffic requires that its operation algorithms include a response to any possible situations, the specialists of NIIAS JSC and Russian Railways JSC developed and approved 39 scenarios [5]. All possible variants were thought out, actions of all systems and participants of the transportation process were prescribed and coordinated. Six scenarios describe normal operation of systems and include the departure and arrival of electric trains from/to coach yards and depots, following the route, passenger embarkation and disembarkation. The largest group of scenarios describes the operation of systems in abnormal situations (derailment of rolling stock, heating or destruction of axle units, an obstacle on the electric train's route, running over a person, etc.). 16 scenarios take into account the occurrence of various train or infrastructure faults (see *Fig. 4*).

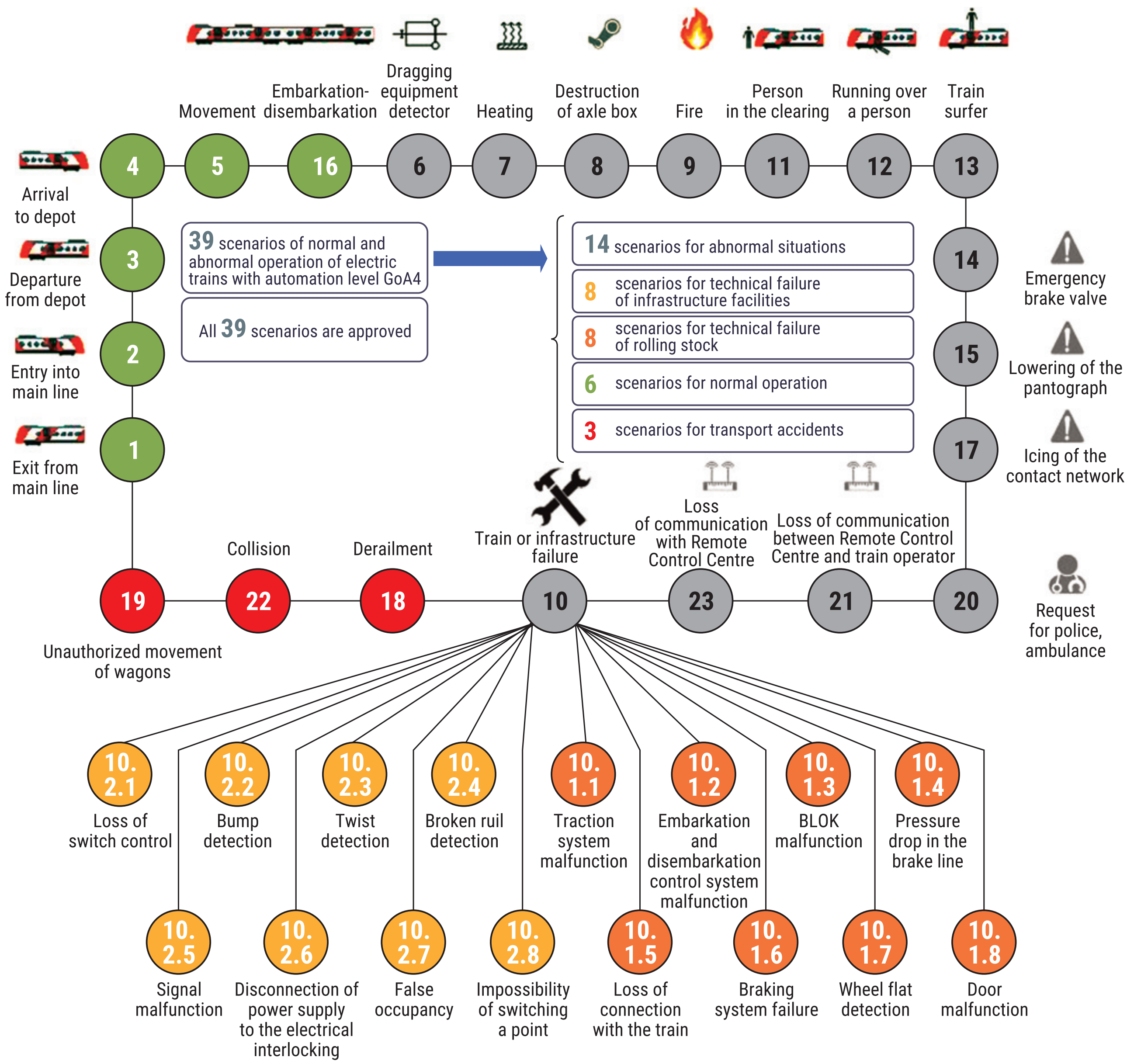

Fig. 4. Baseline operational scenarios on the MCC

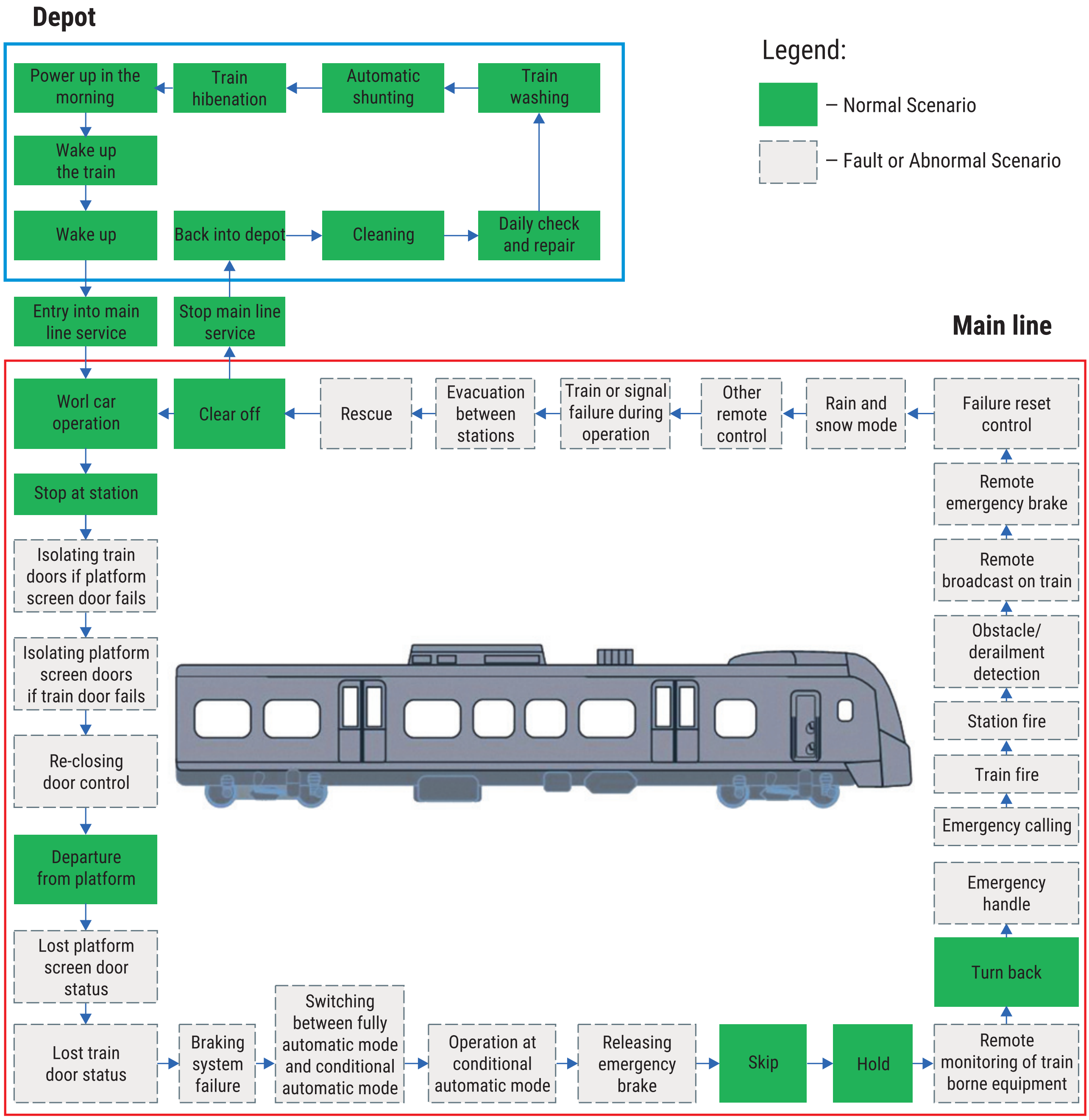

Fig. 5. Basic scenarios of unmanned transport operation

The developed scenarios are tested in a simulator and also drilled at the actual site of system implementation. The time and nature of the systems' response are specified and the personnel's actions are verified. In the course of pilot operation of electric trains in automatic mode, scenarios can be modified and their number can be increased.

In general, the development and refinement of scenarios should take into account a wide range of factors, including the specifics of train traffic management and regulatory requirements of each individual country, local features of the infrastructure, dispatch control systems, signalling, radio communication, diagnostics and monitoring devices, as well as transport safety equipment used on a particular urban railway. *Figure 5* shows a set of basic universal scenarios that can be taken into account and adapted to the operational requirements of a particular railway in BRICS countries.

AUTOMATIC OBSTACLE DETECTION SYSTEM

From a technical point of view, an automatic control system should be built on the basis of modern digital sensors and digital methods of processing information about the train situation using computer vision methods and artificial intelligence technologies that allow for timely detection and classification of foreign objects on the tracks to make a decision on the appropriate response of the unmanned train [6]. Radars, lidars, video cameras, thermal imaging cameras, and ultrasonic sensors are used as these sensors. They function in different ranges of the electromagnetic spectrum and have their own advantages and disadvantages which can be manifested under different conditions of light, humidity, dust, etc. Settings are selected based on the ambient conditions and operational tasks for the rolling stock.

Data from the sensors are processed using artificial intelligence technologies that allow for detecting a railway track, detecting obstacles and infrastructure objects, classifying the objects found, estimating the depth from the camera data, detecting anomalies, and so on. It is important to note that the system is able to detect and recognise only those objects that it has been trained to detect, so a significant issue remains the availability and accessibility of datasets from sensors on which the necessary objects are labelled [7]. For railway transport, a set of public datasets is extremely limited compared to, for example, the road transport sector. Access to railway infrastructure is limited, and the creation of a high quality labelled dataset has a high cost, so if a company is involved in its preparation, most often the dataset is not made freely available. Among the open datasets in the field of railway transport, we can mention several [8]:

- RailSem19 — 8,500 images of railway and tram scenes from 38 countries;
- FRSign — 105,352 images of French railway signals labelled with frames;
- GERALD — 5,000 images of German signals;
- RAWPED — 26,000 images of pedestrians labelled with frames;
- OSDaR23 — 1,534 labelled images and 204,091 objects to be labelled.

A limitation of most available datasets is that they only represent certain scenarios, environments and components. Track elements, rolling stock and climate may vary from country to country, so datasets created in one environment are not always suitable for training systems operating in other environments. There are several open datasets available in Russia, created by the St. Petersburg branch of NIIAS JSC. Four datasets are available for download at datasets.vniias.ru, and all interested users are invited to solve real problems on detection and segmentation of railway transport and infrastructure facilities.

RADIO COMMUNICATION INFRASTRUCTURE

The transition to unmanned traffic is virtually impossible without the introduction of broadband radio communications with a significantly higher bandwidth, which will enable the implementation of such functions as video streaming. Given that the existing GSM-R radio communication system is narrowband and cannot be adapted to the increasing information flow, in 2014, the International Union of Railways (UIC) initiated the FRMCS project aimed at preparing for the implementation of a new digital radio communication system for railways. The 5G standard was chosen as the communication standard on the basis of which the FRMCS system is being developed. This standard provides for a high bandwidth and is optimised for the creation of highly reliable data networks with ultra-low signal delay.

It should be noted that the implementation of communication systems based on the 5G technology on trunk lines is limited by the high cost of their construction. A possible and promising alternative may be the use of satellite communication systems that are currently being actively implemented in Russia. Thus, within the framework of the Sfera project, Roscosmos State Corporation launched the Skif-D demonstration communications satellite to test technologies for creating an orbital constellation for a broadband Internet system. It is planned that the Skif satellite constellation will consist of 12 spacecraft [9]. By the end of 2024, the Marathon–IoT spacecraft is expected to be launched, which will provide communication with ground-based sensors and control systems, including trains. The full-scale orbital constellation ‘Marathon–IoT’ will include 264 spacecraft [10]. Interesting is the solution of Bureau 1440, which launched three spacecraft ‘Rassvet’ in 2023. The satellite supports a data transfer rate of 12 megabits per second with a delay of only 41 milliseconds. This speed is enough to implement remote control of trains. According to the company’s plans, 250 satellites will be launched at the first stage to provide basic coverage, and by 2030 their number will increase to 700 satellites, which will provide global coverage [11]. The development of such technologies will significantly facilitate the development and implementation of unmanned railway technologies in remote areas.

CHALLENGES AND PROSPECTS FOR THE INTRODUCTION OF UNMANNED TECHNOLOGIES

In terms of the prospects for the introduction of unmanned technologies, the most accessible is the deployment of such systems at marshalling yards where LTE broadband has already been deployed. Low traffic speeds, short braking distances and the absence of other types of traffic make it easier to create an automatic train control system. In Russia, an unmanned shunting locomotive has already started operating at the Luzhskaya marshalling station in 2017. At the moment, three fully unmanned locomotives equipped with an obstacle detection unit, which includes radars, lidar and cameras, are operating at the station. Movement along the set route, approach to wagons, coupling with wagons and pushing wagons onto the marshalling yard are performed in a fully automatic mode. The locomotives are monitored by driver-operators at the control centre, who make decisions in emergency situations and can remotely control the locomotive via the remote control panel.

Another promising application of automation technologies is the introduction of unmanned goods trains. An Australian mining company, Rio Tinto Limited, has become a pioneer in this area by introducing unmanned long-distance heavy-haul trains with GoA4 grade of automation on its railway network. The company worked with Hitachi Rail STS S.p.A. to implement the AutoHaul project, which has increased the network capacity and reduced the time it takes to deliver iron ore from mines in the Pilbara region to port terminals in Dampier and Cape Lambert. The full transition to automatic train control took place in June 2019 [12]. All activities that were previously performed manually by the driver are now taken over by ATO systems and, if necessary, by driver-operators from the control centre located in Perth, 1,500 km from the mine [13].

Rio Tinto locomotives were equipped with new systems, including a collision avoidance system, a safety system that monitors the train speed, and on-board cameras that allow for continuous monitoring from a control centre [14]. To identify potential threats on the train track, the locomotives were equipped with an advanced artificial intelligence-based obstacle detection system created by Rail Vision Ltd., Israel. The system detects obstacles in a given area at a distance of up to two kilometres in virtually all weather and light conditions, after which it classifies the obstacles and generates visual and audible warnings for the driver-operator and dispatcher in real time [15, 16].

Special attention was paid to the existing level crossings on the network, which were identified as the highest risk locations during the AutoHaul project development. The crossings were equipped with lighting, video surveillance and laser obstacle detection systems, which are connected to an ALS (automatic locomotive signalling) system. High-resolution (4K) video cameras were used, allowing for a good overview of the situation at a crossing from the control centre.

However, it should be noted that Rio Tinto has an isolated railway network with only company-owned homogeneous rolling stock, so replicating the technical solutions implemented in the Pilbara region on railways with different conditions may not be sufficient to ensure safety.

The main issues to be solved during the implementation process are as follows: ensuring reliable broadband communication between trains and the control centre, improving the reliability of rolling stock, and solving problems associated with the occurrence of abnormal situations. And, of course, the transition to such technology should be carried out sequentially. At first, it is necessary to implement the one-person operation (OPO) technology (where a train is operated by the driver alone, without an assistant driver) on goods trains. Then it is possible to implement partial automation, for example, to create unmanned pusher locomotives. It is possible to launch a package of goods trains where the crew is present on only one train. The task of railway scientists is to work out the technological aspects of various implementation options and determine the further development path of automation in freight transport. In general, in the near future, unmanned goods trains may be in demand in almost all BRICS countries.

When automating passenger railway traffic, additional challenges arise. It is necessary to create a system for controlling the embarkation and disembarkation of passengers and ensuring their safety, to provide for the possibility of communication between a passenger and a railway employee, etc. Different countries around the world are implementing some kind of train automation projects. In Germany, as part of the Sensor4Rail research project, an electric train was equipped with a machine vision system and field tests were conducted [17]. In 2021, France's national railway operator SNCF launched a prototype passenger train which ran on a commercial mainline railway in a test mode and recorded data to improve signal recognition algorithms [18]. Interest in automatic train control has also been observed in BRICS countries. For example, in China, TCT has developed an obstacle detection system using artificial intelligence technologies and received a SIL4 safety certificate for it [19]. Indian Railways has held several tenders for the supply and testing of machine vision systems to assist drivers with driving in heavy fog.

Russia is among the leading countries in the development of unmanned trains. At the moment, Russian railways are implementing several projects to automate the movement of locomotives and electric trains. At marshalling yards, the operation of shunting locomotives of various types is being automated. As for electric trains, a large amount of work has been done to achieve the third grade of automation for the ES2G Lastochka train manufactured by Ural Locomotives LLC. Further work is planned to achieve Level 4 for all types of new Russian-made electric trains, including high-speed trains.

Two trains of different versions equipped for GoA3+ automated operation are currently being tested on the

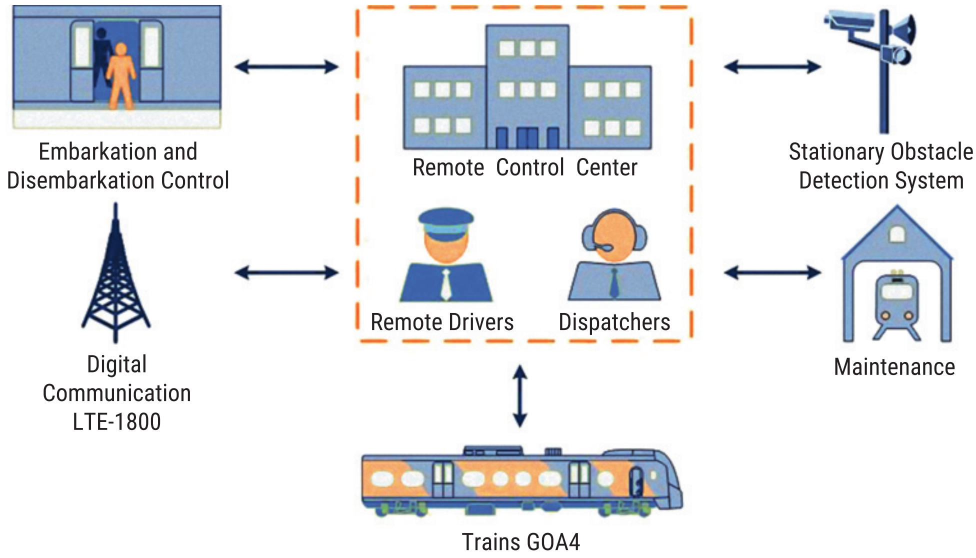

Fig. 6. Unmanned railway transport infrastructure of the MCC

MCC. The trains are equipped with systems for ATO, obstacle detection and positioning on the infrastructure, as well as a communication unit for communicating with the remote control centre. The prototypes can independently follow an energy-optimal schedule, as well as automatically activate braking and stopping algorithms if an obstacle is detected. However, during the tests, there is a driver in the cab of the prototype, who is always ready to take control. Engineers are also watching the train movement and monitoring all the systems of the unmanned train in real time. The infrastructure of unmanned railway transport has been created and tested at the MCC, which is generally universal and can be further standardised for further replication on urban railway transport (*Fig. 6*).

At the same time, the cost of switching to fully unmanned traffic is significant, as it requires investment in both rolling stock and infrastructure. It is necessary to design electric trains and locomotives that are equipped with machine vision, a remote control system, and a new braking system with the possibility of remote control. In fact, all rolling stock units that are now controlled only manually by the driver must be redesigned. In terms of infrastructure, it is necessary to build a digital broadband communication network, build a system for controlling passenger embarkation/disembarkation on platforms, introduce a radio-based collision avoidance system, adapt dispatching personnel's workstations, and build a remote control and management centre for the work of driver-operators. In addition, it is required to train the relevant personnel and make the necessary changes to industry regulations and documents.

A lot of tasks will need to be solved in terms of import substitution. The first machine vision devices were assembled entirely using imported sensors and computing facilities. Currently, the situation is changing, but not radically. At the initial stages, it is probably more correct to speak not so much of import substitution as of technological independence from Western-made components and of achieving sovereignty in this respect. Obviously, it is unlikely that in the coming years it will be possible to organise full production of machine vision devices using domestic components only. But it is possible to organise such production using certain components from friendly countries. In this regard, it is necessary to develop product requirements for domestic manufacturers on the basis of the experience of using imported devices and to carry out gradual replacement of sensors taking into account the requirements of independence from imports.

TECHNOLOGY READINESS OF AUTOMATION SOLUTIONS

If we consider solutions for ensuring the GoA3/4 automation levels of train control from the point of view of their technological readiness level (TRL), currently it varies from country to country. However, in the countries that lead the way, TRLs can be in the range from TRL6 to TRL9.

In assessing the TRL, we rely on the principles laid down in the international standard for defining Technology Readiness Levels and evaluation criteria (see *Table*)[3].

[3] ISO 16290:2013 Space systems — Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment

Table

Technology readiness levels

Technology readiness levels	Description
TRL1	Exploration of basic concepts
TRL2	Formulation of the technology/solution concept
TRL3	Analytical testing of the concept
TRL4	Validation of the prototype in laboratory conditions
TRL5	Validation of the technology/solution components in close-to-real conditions
TRL6	Demonstration of the prototype in close-to-real conditions
TRL7	Demonstration of the prototype in operational conditions
TRL8	Verification of the technology/solution
TRL9	Operationalization of the technology/ solution
TRL9.1	Start of implementation/operation
TRL9.2	Implementation/operation in a limited (pilot) area
TRL9.3	Large-scale implementation (replication)/operation

Taking into account the analyses of GoA3/4 projects in different countries of the world, it can be concluded that at the moment, the efforts are mainly focused on the following:

- Demonstration of the prototype in close-to-real conditions;
- Demonstration of the prototype in operational conditions;
- Verification of the technology/solution).

A separate issue is operationalization of the technology/solution, which primarily concerns rolling stock manufacturers and their willingness to promptly solve the problems of adapting existing designs for the installation of new sensors and equipment, as well as to promptly create new locomotives without a driver's cab.

Of course, for a full-fledged comprehensive assessment of the readiness of a given innovation solution, a number of unified parameters — supporting systems that characterise the development and balance of an innovation project — should be taken into account, namely:

- technology readiness;
- production readiness;
- engineering readiness;
- organisational readiness;
- market readiness.

The criterion that allows for the most correct analysis of the information on unmanned railway systems projects presented above is the technology readiness level (TRL). However, this criterion depends on the influence of a set of factors that are closely interrelated with each other and have different levels of maturity: on-board and wayside equipment, hardware and software, safety and capacity of unmanned transport, quality and efficiency of the 'machine vision' solution under different weather conditions and at different times of the day, relevance of the regulatory framework, etc. In order to objectively assess the TRL, it is necessary to base on the lowest value of the maturity level of the factor that is most significant among those listed above, considering it as a limiting factor. For all unmanned railway systems, the most significant factor is traffic safety, which has a direct impact on the TRL assessment.

A comparison of current trends in the development of railway infrastructure around the world suggests that the level of technology readiness (TRL) should be assessed taking into account the isolation of the system. With regard to the level of automation GoA4, it is currently possible to talk about TRL 9.1 or 9.2 when it comes to projects implemented in depots and marshalling yards or on railway lines operating in a manner that is little different from that of the underground (a closed system with homogeneous rolling stock running at specified intervals). As for mainline and regional railway lines, the level of automation GoA4 is still quite difficult to achieve in terms of practical implementation. Consequently, in this case we can only talk about the level of automation GoA3, which has reached a technology readiness level no higher than TRL 7 or 8.

At the same time, it is necessary to recognise a high intensity of research and testing efforts in the field of unmanned railway transport that are currently taking place in Germany, France, Great Britain, the Netherlands, Russia, China, and a number of other countries. The number of publications on the subject of unmanned transport is increasing, as is the number of patents in this area. Among the BRICS member countries, China is the leader in terms of the number of patents related to automatic vehicle control. NIIAS JSC also actively carries out intellectual activity in the field of unmanned train control. The specialists of the Institute have prepared and registered more than 40 patents and computer programmes, and have written at least 65 scientific publications on this subject.

The active interest in transport automation in the world allows us to assert with a high degree of confidence that as early as by 2026 passenger and/or goods trains with automation level GoA4 may appear in several countries that will operate on limited sections of main and regional railway lines, i.e. corresponding to the technology readiness level (TRL) 9.1.

Thus, 2026 may be the beginning of a new stage in the development of unmanned railway transport. Regulatory and technical documentation developed for obtaining permits to allow fully automatic rolling stock operation and the introduction of relevant amendments to legislation will become a powerful driver for the development of the market for on-board and wayside equipment, as well as hardware and software required for the organisation of safe, energy-efficient and high-performance unmanned railway transportation. The possibility for a large number of equipment manufacturers to participate in tenders for the supply of components for railway systems with the grades of automation GoA3/4 will not only allow for significant price reductions, but will also contribute to the emergence of innovative solutions in the market, which will make it possible to raise the technical characteristics of lidars, radars, ultrasonic sensors, video cameras and other critical components for unmanned trains, as well as the corresponding software to a fundamentally new level. This may also have a significant impact on increasing the investment attractiveness of unmanned railway transport in general.

As for the technology readiness level (TRL) 9.3 of fully unmanned technologies that can be used on mainline and regional railway lines, given the current state of the industry, it is still premature to make any conclusions. This issue is directly related to the timing of verification, validation and standardisation of unmanned train solutions around the world. The speed of development and implementation of FRMCS, a new radio communications standard, may also be a critical factor.

In addition, for a number of reasons, a significant part of railway lines around the world does not allow, in principle, for increasing the level of automation of transportation operations on them to the level of GoA3 without first undertaking large-scale works on their comprehensive reconstruction and modernisation. Consequently, one of the most critical factors for the further development of unmanned transport on mainline and regional lines is the amount of investment allocated for the modernisation and development of railway infrastructure by various countries around the world.

Nevertheless, the use of machine vision as part of modern train control systems is becoming one of the key and long-term trends in the development of modern control systems, which poses a wide range of challenges that require a comprehensive approach. The effective solution of these problems will determine the prospects of a mass transition to fully automatic (driverless) train traffic control, the main condition for which is a guaranteed safety level at least as good as the existing one.

CONCLUSION

Unmanned technologies in the railway industry have broad prospects and are already being implemented, especially in marshalling yards and in isolated, metro-like railway systems. Russia and other countries are actively developing the automation of train control using modern obstacle detection and remote control systems.

Further development of these technologies and the introduction of fully unmanned control on main lines requires significant investment in the modernisation of rolling stock and infrastructure, and also leads to changes in the professional structure. For example, the new profession of driver-operator, who will be responsible for remote control and control of automatic trains in abnormal situations, requires the creation of a workstation that can process a large volume of information and respond promptly to emerging problems. It is also necessary to develop scenarios for the operation of an automatic control system including analysing the actions of all systems and participants in the transportation process in all kinds of situations.

From a technical point of view, automatic train control systems require the use of advanced obstacle detection systems based on digital sensors and information processing methods using computer vision and artificial intelligence to detect and classify objects on the tracks. The main issue to be addressed is the methodology for proving the functional safety of such systems, since the behaviour of an artificial neural network cannot be fully described and predicted. In addition, it is difficult to train artificial intelligence systems. The availability and quality of the datasets required for this represent a limited and costly aspect, especially in the railway industry.

Another crucial challenge is setting up information transmission systems. The transition to unmanned traffic in the railway industry requires broadband radio communications with a high capacity, which requires the introduction of new communication systems, such as 5G. However, the implementation of 5G on trunk lines is costly, which makes the alternative satellite communication systems attractive.

It is advisable to introduce unmanned technologies in stages, starting with partial solutions and gradually moving to full automation. It is also necessary to take into account the issues of import substitution and technological independence when developing and implementing new systems.

These tasks on the BRICS railways can be achieved by combining the efforts and resources of railway administrations and sectoral institutions, including through the creation of the Railway Research Network. This coordination mechanism could become a platform for promoting railway initiatives, exchanging innovations, as well as helping to resolve issues related to the development and manufacture of components and parts for ATO systems. It seems reasonable to undertake a joint benchmarking study to be followed by the elaboration of a common strategy for the development of autonomous railway transport. The research network can become a common knowledge base and serve as an expert body for the creation and implementation of various innovative solutions on the BRICS railway network in areas such as collision avoidance, train traffic control and safety systems, process simulation, digital communications, intelligent diagnostics of rolling stock and infrastructure, satellite and geoinformation systems, etc. The network will also be able to develop and implement various innovative solutions on the BRICS railway network. The exchange of competencies, best practices, technological solutions and approaches to railway development will contribute to improving the quality and attractiveness of railway transport services in the BRICS countries.

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Potential for the Development of International Transport Corridors in Current Market Conditions

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ABSTRACT This research is devoted to the prospects for the development of international transport corridors (ITC) through the prism of the dynamics of market forces in the transport industry and world trade.

International logistics is currently undergoing a global transformation, and therefore the effective use by Russia of its transport potential is still the most urgent and practical task. In this regard, this research is focused on internal and external factors that influence the realization of this potential.

The research presents the factors that contributed in retrospect for more than 10 years to the dynamic development of freight transportation through the ITC "East – West". Additionally, the impact of exogenous factors such as epidemiological restrictions on a global scale and economic sanctions against Russia on the logistics of container transportation in recent years is considered in more detail.

On the basis of a retrospective analysis of the development of cargo transportation through the ITC "East – West" generalized conditions are formulated that allow to assess the potential for the development of transport cargo flows on other key ITC.

An analysis of the current dynamics and problems of the development of transportation along the corridors East – West, Northern Sea Route and North-South is carried out. Further prospects for their increase from the point of view of transport marketing is provided.

Among the conclusions, the importance of developing and expanding the infrastructure of the ITC "East – West", as well as proposals for the intensification of cargo transportation through other ITC, is highlighted.

KEYWORDS: international transport corridors; ITC "East – West"; ITC "North – South Corridor"; ITC "Northern Sea Route"; the impact of the COVID-19 pandemic on logistics; conditions for the successful development of international logistics; problems of development of international transport corridors; development of international container transportation; traffic statistics on international transport corridors; and development of international trade.

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Научная статья

Потенциал развития международных транспортных коридоров в текущих рыночных условиях

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АННОТАЦИЯ Исследование посвящено перспективам развития международных транспортных коридоров (МТК) через призму динамики рыночных сил в транспортной отрасли и мировой торговли.

Поскольку в свете глобальных трансформаций в международной логистике последних лет наиболее актуальной и практической задачей продолжает оставаться получение Россией максимальных выгод от своего транспортно-географического положения, основное внимание уделено внутренним и внешним факторам, оказывающим влияние на реализацию этого потенциала.

Представлены факторы, способствовавшие в ретроспективе более 10 лет динамичному развитию грузоперевозок по МТК «Восток – Запад». Более подробно рассмотрено влияние на логистику контейнерных перевозок последних лет последствий таких экзогенных факторов, как эпидемиологические ограничения в мировом масштабе и экономические санкции в отношении России.

На основе данного анализа сформулированы обобщенные условия, позволяющие оценить потенциал дальнейшего увеличения транспортных грузопотоков по другим МТК.

Произведена оценка текущей динамики и проблематики перевозок по коридорам «Восток – Запад», «Северный морской путь» и «Север – Юг», а также оценка дальнейших перспектив их увеличения с точки зрения транспортного маркетинга.

В числе выводов обозначена важность развития и расширения инфраструктуры МТК «Восток – Запад», приведены предложения по интенсификации грузоперевозок через другие МТК.

КЛЮЧЕВЫЕ СЛОВА: международные транспортные коридоры; МТК «Восток – Запад»; МТК «Север – Юг»; МТК «Северный морской путь»; влияние пандемии COVID-19 на логистику; условия успешного развития международной логистики; проблематика развития международных транспортных коридоров; развитие международных контейнерных перевозок; статистика перевозок по международным транспортным коридорам; развитие международной торговли

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INTRODUCTION

This research is devoted to the prospects for the development of international transport corridors (ITC) through the prism of the dynamics of market forces in the transport industry and world trade.

Since, in the light of global transformations in international logistics in recent years, the most relevant and practical task is to maximise the benefits of Russia's transport and geographical position, the main focus is made on internal and external factors that influence the realisation of this potential.

Due to the fact that international trade is mainly carried out in large-capacity containers as the most technologically advanced mode of transport, the data and conclusions are presented in the context of the development of multimodal container transport.

As per the generally adopted classification[1] the main international corridors passing through the territory of Russia are as follows (*Fig. 1*):

- North – South Corridor (Eastern Branch, Western Branch and Trans-Caspian Route);
- East –West Corridor (North Eurasian Route and Central Eurasian Route);
- Northern Sea Route Corridor.

Analysing the development potential of these corridors is impossible without understanding the reasons that, to a greater or lesser extent, allow the development of cargo turnover on a large scale.

Further, by the example of retrospective analysis of traffic through the East – West ITC, the key factors that make it possible to assess the potential for prospective development of international transport routes have been formulated.

JUSTIFICATION OF THE METHODOLOGY FOR THE ASSESSMENT OF THE TRANSPORT CORRIDORS POTENTIAL

“East – West” ITC should be subdivided into two routes:

- The Northern Eurasian Route is a route along the Trans-Siberian Railway, starting from ports and border crossings in the Primorsky Krai, the main border crossings at present being Zabaikalsk – Manchuria and Zamyn – Uud – Erlian (Mongolian Railway border crossing with Chinese railways) and proceeding first of all to Brestskaya border crossing Naushki of Russian railways. railway) with Chinese railways, cargo flows through which further go through the Naushki border crossing of Russian railways) and the following first of all to the Brest – Malaszewicz border crossing on the border of Poland and Belarus;
- Central Eurasian Route — the route through Kazakhstan via the Dostyk – Alashankou and Altynkol – Khorgos border crossings with China and onwards to the Brest – Malaszewicz border crossing.

There are also alternative branches to the west through which shipments can be made, such as routes through other border crossings in Belarus, ports in

[1] Federal target subprogramme ‘International Transport Corridors’. URL: https://fcp.economy.gov.ru/ext/11/3.htm

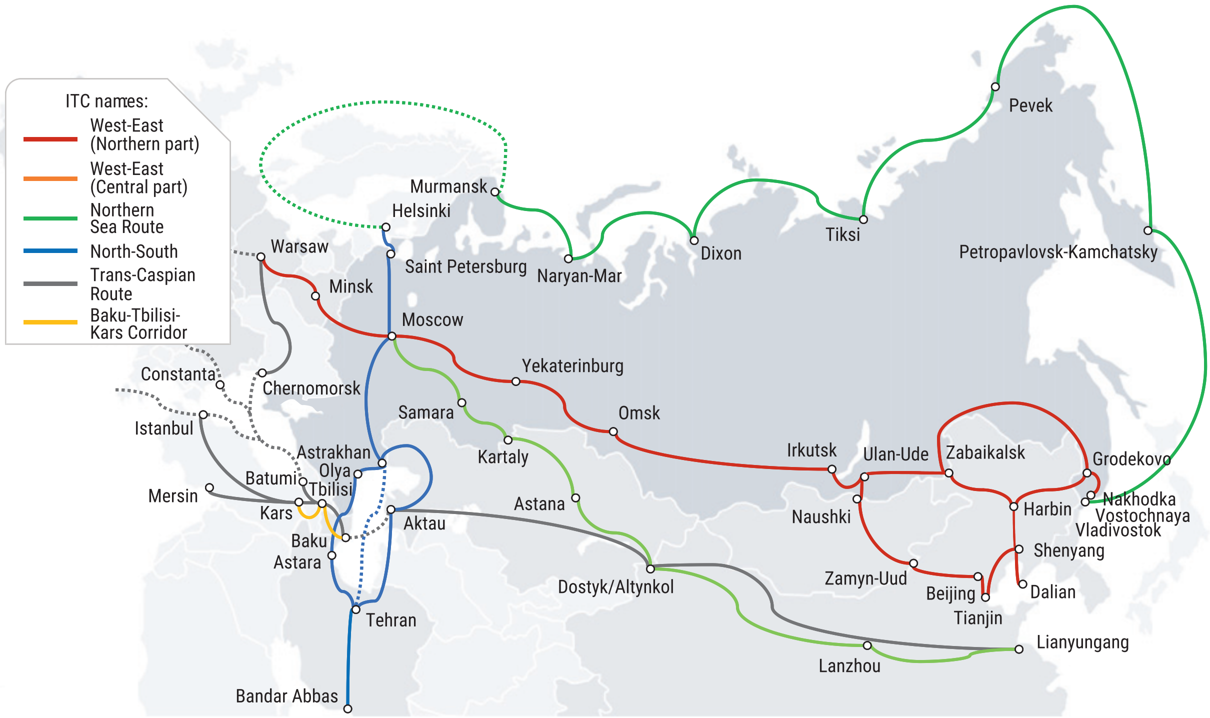

Fig. 1. Main international transport corridors across Eurasia[2]

Saint Petersburg, and border crossings in Kaliningrad Region.

The first important milestone in the development of the East – West Corridor, namely its Central Eurasian route, was the cancellation of customs procedures at the borders of Russia, Kazakhstan and Belarus in 2011, which subsequently increased the speed of delivery of goods between Europe and China and reduced the cost of paperwork[3]. In addition, the use of the unified CIM/SMGS consignment note was gaining popularity during this period[4].

The second key development was the launch in 2012 by Chinese provinces of subsidies for rail transport through land border crossings, thereby making it more attractive to China's central and northeastern provinces compared to multimodal transport through Pacific ports[5].

The third milestone in the development of the East – West corridor was the establishment of a single logistics operator, OTLK ERA, JSC (formerly OTLK, JSC), at the end of 2014 and the systematic development of Kazakhstan's border crossing infrastructure, in particular, the commissioning of the large dry port KTZE – Khorgos Gateway and the Altynkol – Khorgos border crossing in 2015[6].

Transportation on the route operated by OTLK ERA is also subject to a discount to the tariff of three railway administrations (Russia, Belarus and Kazakhstan), which has made it possible to stimulate the growth of traffic volumes since the launch of the operator.

In aggregate, the above non-market support mechanisms have contributed to a 14.3-fold increase in transit volumes of Europe – East Asia – Europe via the Central Eurasian route from 2014 to 2019, from 21,000 twenty-foot equivalent containers (TEUs) to 305,000 TEUs.

Notably, even with subsidies from the Chinese provinces, the lack of a significant financial incentive similar to that in place for OTLK ERA transports and the nominated single transport organiser, as well as the slower speed of cargo (for 2022 in average, 5–6 days

[2] The graphic representation was generated by the author on the basis of public sources.
[3] Decree of the President of the Russian Federation dated 01.07.2011 No. 880 'On Cancellation of the Agreed Types of Control on the State Border of the Russian Federation with the Republic of Belarus and the Republic of Kazakhstan' // Rossiyskaya Gazeta. 12.07.2011.
[4] Viksne D. Document for two systems // Gudok. 20.07.2011. URL: https://gudok.ru/newspaper/?ID=690683
[5] Stimulating Export Railway Transport in China: Results and Prospects: An Information and Analytical Review // Eurasian Rail Alliance Index. URL: https://index1520.com/upload/medialibrary/7b0/9576l2q9fz9dwfktahjrdm370w142dh9/ERAI-Subsidies-RU.pdf
[6] Tonkonog O. The Way the Largest Dry Port in Central Asia Works // Sputnik News Network Agency. Kazakhstan. 01.10.2020. URL: https://ru.sputnik.kz/20201001/krupneyshiy-sukhoy-port-15108603.html

via Dostyk –Altynkol border crossings to the border of Poland and Belarus versus 8–10 days on the same route via Zabaikalsk) became one of the reasons for relatively low dynamics of transit volumes development between Europe and East Asian countries via the infrastructure of the Northern Eurasian route.

The growth of overland transport volumes along the East – West ITC in 2016-2019 occurred under the following circumstances:

- practically unchanged level of sea freight rates (in the range of $2,000 per FEU on the Rotterdam – Shanghai – Rotterdam route[7]);
- growth of sea freight volumes on the Europe – East Asia – Europe Route[8];
- an increase in the share of containerised shipments within the PRC from 4.5–9.0% in 2016 to 5.1–10.3% in 2019 (estimate based on data from the State Statistical Office of the PRC in terms of 10–20 tonnes/DFE[9]);
- overall growth in the volume of trade between the countries of these regions[10].

The growth of East-West ITC traffic volumes in 2020–2021 should be considered separately due to the specific conditions of the COVID-19 pandemic, which caused trade restrictions and changes in transport logistics.

The impact of the epidemiological restrictions in the first half of 2020 was a decrease in global trade volumes, a decrease in shipping orders, a disruption of international logistics chains, and an accumulation of empty containers in Europe and North America.

In the second half of 2020, governments, particularly in China, began to gradually ease quarantine restrictions, which led to an explosive growth in demand for maritime transport (according to LLI Consulting, 10 times more than in the first half of 2020[11]).

Against this background and the shortage of empty containers for loading in China (in December 2020, the FEU availability index in the port of Shanghai CAx decreased to 0.02 points[12], which indicates an acute shortage of containers and a predominance of shipments from the port over arriving containers), which had by then accumulated in large volumes in North America and elsewhere. International shipping lines have had to include their freight rates in the cost of redeploying empty containers and even the production of new containers in China (in the first half of 2021 alone, the production of new containers surpassed that of the whole of 2020[13]) to ensure the export of cargo out of the country. In this regard, the January 2021 global container index (WCI) has doubled by November 2020[14].

From the second half of 2021, the situation was exacerbated by the increased imbalance of trade flows between Europe and Asia against the background of a faster recovery of the Chinese economy from the crisis associated with the COVID-199 pandemic, which led to a significant utilisation of sea container terminals in Europe (at the end of 2021, the utilisation index of sea container terminals in Europe doubled compared to the end of 2020[15]).

The above factors caused a partial shift of cargo flows in 2020–2021 from sea transport in favour of transit railway services within Russia — transit through the Russian Railways network in 2021 for the first time exceeded 1 million TEUs[16], showing growth of 34.4 % compared to 2020, while traffic on all routes of the East-West ITC corridor increased by 2.3 times by the pre-pandemic year 2019 (*Fig. 2*).

However, against the background of a slowdown in global trade in 2022[17], as well as port offloading and increased maritime turnover, freight rates

[7] World Container Index assessed by Drewry // infogram. URL: https://infogram.com/world-container-index-1h17493095xl4zj
[8] Transport, Postal and Telecommunication Services. Freight Traffic // National Data. National Bureau of Statistics of China. URL: https://data.stats.gov.cn/english/easyquery.htm?cn=C01
[9] Volume of containers transported to/from main ports — quarterly data (2015–2016) // Eurostat. URL: https://ec.europa.eu/eurostat/databrowser/view/MAR_GO_QM_C2016/default/table?lang=en
[10] EU trade since 1988 by HS2-4-6 and CN8 (former content) // Eurostat. URL: https://ec.europa.eu/eurostat/databrowser/product/view/ds-045409?category=ext_go.ext_go_detail
[11] LLI Consulting. Volume of orders // infogram URL: https://infogram.com/lloyds_list
[12] Container Availability Index // Container xChange URL: https://www.container-xchange.com/features/cax/
[13] Containers are being built at a record pace. It's still not enough // Freight Waves. 27.07.2021. URL: https://www.freightwaves.com/news/containers-are-being-built-at-a-record-pace-its-still-not-enough
[14] World Container Index // Drewry. URL: https://www.drewry.co.uk/supply-chain-advisors/supply-chain-expertise/world-container-index-assessed-by-drewry
[15] Port congestion in key Europe, US gateways continues to deteriorate: Sea-Intelligence // S&P Global. Commodity Insights. 12.01.2022. URL: https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/shipping/011222-port-congestion-in-key-europe-us-gateways-continues-to-deteriorate-sea-intelligence
[16] Russian Railways summed up the results of their operation for 2021 // The Federal Railway Transport Agency. 15.03.2022. URL: https://rlw.gov.ru/press/document/11871
[17] Global container trade volumes 2017–2024 // infogram. URL: https://infogram.com/container-trade-volumes-1hnp27nljyoy4gq

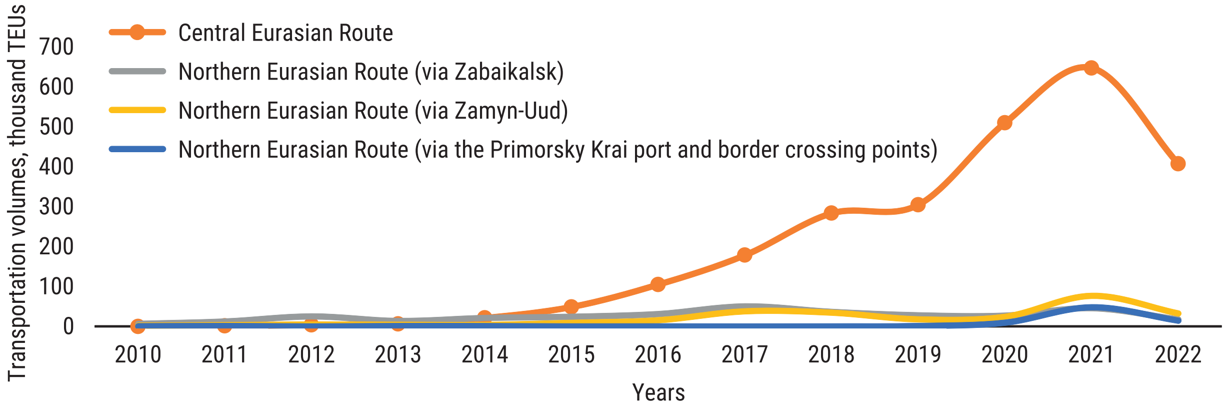

Fig. 2. The volume of traffic on the routes and branches of the East – West Corridor between Europe and East Asia in 2010–2022[18]

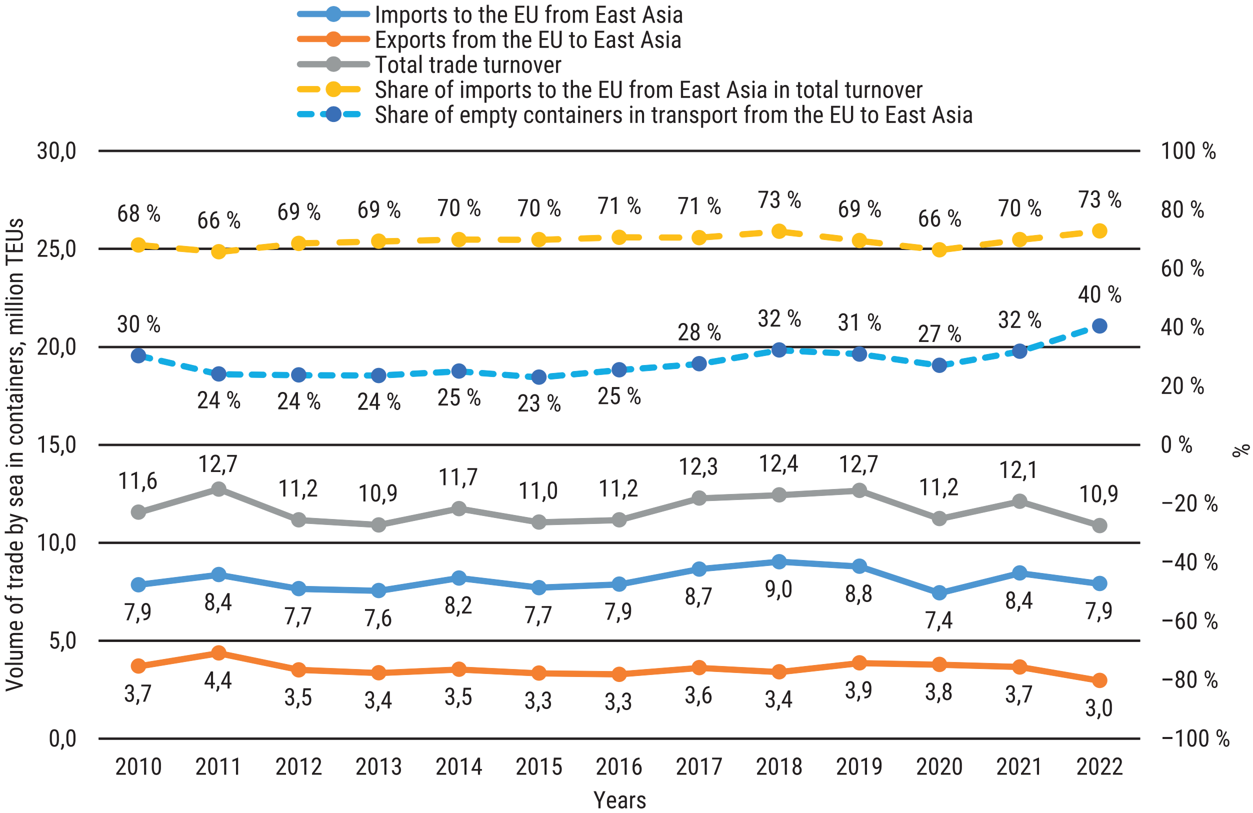

Fig. 3. The volume of loaded containers transported by sea in Europe and East Asia in 2010–2022, with indicators on the ratio of imports in trade and the share of empty container adjustments[19]

declined from the beginning of 2022 and actually reached their historical average level by the end of the year[15].

For this reason, as well as sanctions restrictions against Russia in 2022, international freight forwarders again began to favour maritime transport along the China – Europe – China route, and transit volumes along the East – West ITC decreased.

These developments illustrate to a greater extent the transport market environment, which is derived from trade between Europe and East Asia.

An important feature of trade between the two regions over the last decade has been the lack of balance in cargo flows in terms of logistics — the volume of East Asian exports by sea has been 2–3 times higher than European exports to the region since at least 2010 (*Fig. 3*).

[18] The graphic representation was formed by the author on the basis of data of Russian Railways, JSC and other public sources.
[19] The graphic representation was created by the author on the basis of Eurostat data.

This imbalance forces logistics companies to send empty containers from Europe by sea back to East Asia — the share of such shipments is around 30 per cent, with the share reaching 40 per cent in 2022[9].

In rail transport there is also an imbalance of cargo flows and redeployment of empty containers, but the share of empty containers in the container traffic from Europe to East Asia from 2020 to 2022 did not exceed 15 %, and in the first half of 2023 there were no shipments of empty containers (including due to sanctions restrictions).

The imbalance of cargo flows is not an obstacle to dynamic trade between the two regions, possibly due to low freight rates for empty container relocation, as well as a generally low transport component in the price of shipped products on at least one side of the trade.

A rather low transport component in the price of products is characteristic of exports from East Asia to Europe — at least 50 % of these shipments are such high-value cargoes as electrical machinery and equipment, engines, power plants, plastics, petroleum products, ferrous metal products, chemicals, cars, furniture, etc. The share of high value-added products in exports from Europe to East Asia is about 20 %[20].

From the presented analysis, it is possible to summarise at least the following conditions for the successful development of international transport corridors:

1) the sufficiency of infrastructure and quality of service on the route, including technical and technological capabilities for the transport of certain nomenclatures of goods;

2) the availability of harmonised legislation and absence of unproductive transactions in trade between countries, the number of which can be reduced both by simple cancellation and their digitalisation and automation;

3) a price level satisfactory to the participants of the transport process, which can also be achieved through non-market mechanisms;

4) conditions of balance of counter cargo flows on the basis of logistic principles (minimum empty equipment adjustments), otherwise the costs of empty equipment adjustments should be not very noticeable in the price of goods or satisfy their buyers (also related to the previous point);

5) the availability of large volumes of cargo base and prerequisites for trade turnover between trading states, which is a consequence of a wide list of factors of both geopolitical, economic and cultural nature;

6) the availability of a nominated transport organiser (it can be assumed that this is not a mandatory condition, however, when developing new interstate routes in conditions of uncertainty, participants of the transport process first of all turn to 'official' providers of services).

THE RESULTS OF TRANSPORT CORRIDOR POTENTIAL ASSESSMENT

Let's consider the development potential of each ITC through the prism of these conditions.

The freight base for rail transport in transit through Russia between East Asia and Europe will remain significant in the long term, and the development of such traffic will be subject to a number of risks and factors that are difficult to predict.

The key one will be the reduction of subsidies for freight transport to Europe by Chinese provinces and, according to some sources, the complete abandonment of this mechanism by the end of 2023[21].

The long-term operation of the subsidy mechanism has led to the formation of a stable pool of railway transport customers for whom the price of transportation is less important and the stability and speed of freight movement is a priority5. For this reason, the reduction of financial incentives will lead to the fact that land transit will be carried out along the most optimal route in terms of quality and price, for which the Central Eurasian route has the greatest claim (of course, within the limits of capacity). At the same time, railways will mainly transport cargoes that are least sensitive to the growth of transport costs (high value-added products) and most susceptible to the negative impact of natural factors when transported by sea (sea air and high ocean humidity).

In particular, such cargo will be automobiles and components for them, the growth of shipments from China to Europe in the first half of 2023 was about +60 % compared to the second half of 2022 or 2.5 times compared to the first half of 2022, which reflects the long-term trend of expansion of the Chinese automotive industry in the European market.

Despite this and the growth in world trade projected by many international organisations for 2024[22], the

[20] EU trade since 1988 by HS2-4-6 and CN8 (former content) // Eurostat URL: https://ec.europa.eu/eurostat/databrowser/product/view/ds-045409?category=ext_go.ext_go_detail

[21] Sam Whelan. It'll be 'quality not quantity' on China-Europe rail services as subsidies fade // The Loadstar. 20.12.2021. URL: https://theloadstar.com/itll-be-quality-not-quantity-on-china-europe-rail-services-as-subsidies-fade/#:~:text=He%20told%20The%20Loadstar%3A%20"China's,at%20a%20much%20lower%20level

[22] The global recovery is slowing amid widening divergences among economic sectors and regions // International Monetary Fund. URL: https://www.imf.org/en/Publications/WEO/Issues/2023/07/10/world-economic-outlook-update-july-2023

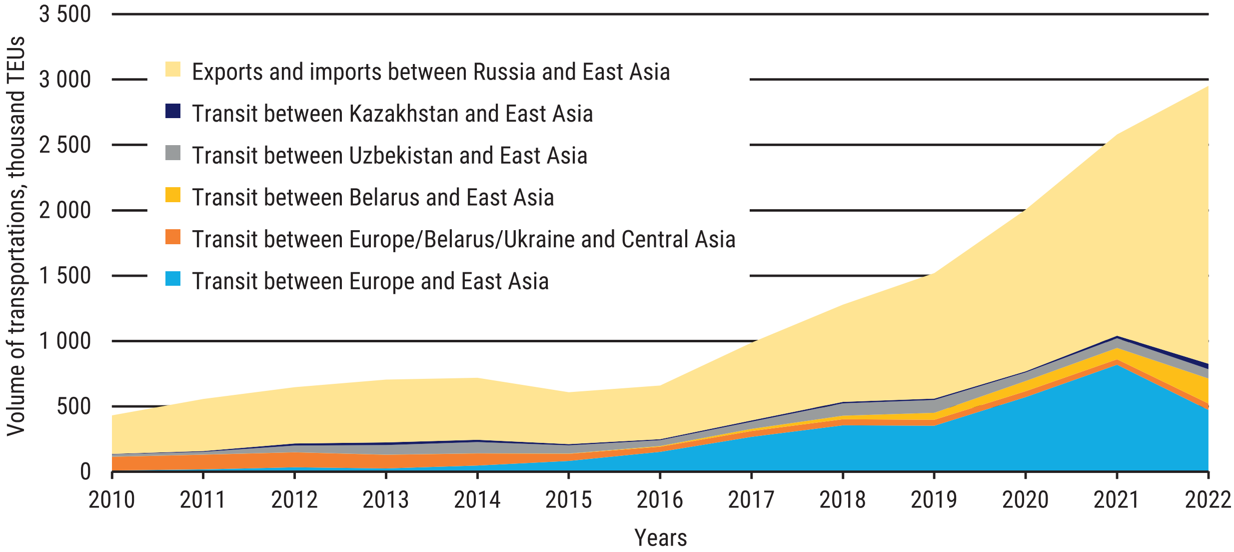

Fig. 4. Volume of East – West ITC traffic by main cargo flows[23]

risks for the development of trade between East Asia and Europe will remain, on the one hand, the reduction of effective demand in Europe and the reduction of economic and production potential of the region due to high energy prices (according to Bloomberg forecasts, the decline in EU GDP could be up to 5 per cent in 2024[24]), which will aggravate the situation with the imbalance of trade relations and rising transport costs, on the other hand — the slowdown of China's economy (according to the International Monetary Fund from 5.3 % in 2023 to 4.5 % in 2024).

Lack of prerequisites to increase freight rates to favourable rates for rail transport against the background of increasing capacity of the global maritime fleet[25] will also be a barrier to continued strong growth in East-West ITC traffic until 2021.

In this regard, the potential for further growth of transit between East Asia and Europe is extremely low, unless any of the parties to the transport process will not undertake radical non-market mechanisms to stimulate these transportations.

As a matter of fact, in the first half of 2023, the Russian operator business records a reduction in demand and traffic on the East – West ITC between the two macro-regions.

This, in turn, forces transport market players, including with the support of the Government of the Russian Federation, to look for alternative opportunities for the development of interstate transport.

At present, it is possible to group two visible vectors of endeavours:

- increasing the connectivity of Eurasian states to enhance trade across the mainland;
- development of transport services via ITC, independent from the transport infrastructure of 'Western' countries.

Thus, the lost traffic volumes on the East Asia – Europe – East Asia route were partially replaced by Belarus – East Asia traffic, and the East – West ITC infrastructure became more utilised for increased exports and imports between Russia and China (mainly through ports in the Primorsky Krai). The total volume of traffic along the corridor, irrespective of Russian restrictions, increased by 31 % in 2022 compared to 2021, when transit volumes between Europe and Asia were at their highest level ever (*Fig. 4*).

Given that the European market for Russian producers has closed due to sanctions, there are currently no other options for the use of this corridor, the volume of traffic along this corridor will continue to depend on the capabilities of the Eastern polygon infrastructure and the priorities of Russian Railways, JSC and the Government of the Russian Federation in the passage of certain nomenclature groups of cargo.

It should be noted that the volume of shipments from Belarus will also depend not only on the country's domestic production and the market potential for the sale of its products in East Asia, but also on the volumes

[23] The graphic representation was formed by the author on the basis of data of Russian Railways, JSC and other public sources
[24] Bloomberg warned of a 'painful reckoning' for the EU economy // RBC. Economics. 07.08.2023. URL: https://www.rbc.ru/economics/07/08/2023/64d07eec9a79476353fd865a
[25] Drewry reports 6 million TEU of surplus containers // Container News. 14.07.2022. URL: https://container-news.com/drewry-reports-6-million-teu-of-surplus-containers/

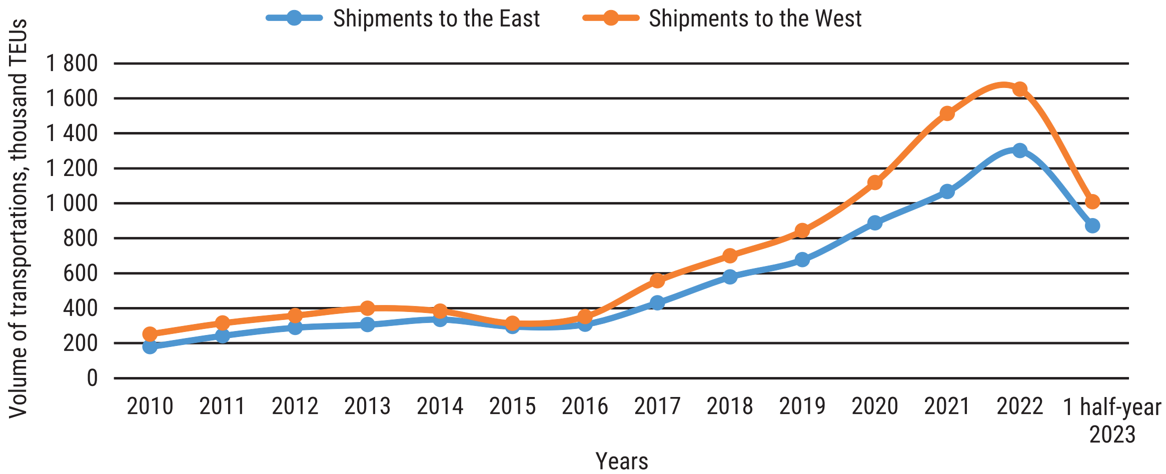

Fig. 5. East – West ITC shipments by direction (export, import and transit)[26]

of shipments agreed with the Russian side along the East – West ITC.

Despite the seemingly inexhaustible in the near future potential for increasing trade and transport volumes between Russia and China (potential growth by 2030 more than 2 times by 2022 in monetary terms [1]), the further development of container cargo traffic along the ITC 'East – West', in addition to expanding the capacity of the infrastructure of Russian Railways, JSC, will be affected by the following circumstances and risks:

- potential reduction of transport subsidies by Chinese provinces, which currently also applies to imports into Russia;
- weak ruble exchange rate, which makes imported goods less affordable for the country's population and, consequently, reduces demand for them;
- falling incomes of the population inside the country, which is a risk for further dynamic increase in sales of imported products (nevertheless, even in the conservative scenario of the Ministry of Economic Development's forecast for 2024, real disposable incomes of the population are growing[27], International agencies are also optimistic about Russia's economic growth prospects[28]);
- as previously mentioned, the decrease in the pace of China's development;
- increased transport costs due to the accumulation of equipment in the western regions of Russia, its local deficit in the east of the country and the need for empty adjustments, which is a consequence of imbalance of counter container flows (*Fig. 5*).

The problem of imbalance of counter cargo flows has become so urgent that Russian Railways, JSC has been forced since October this year to apply non-discriminatory access rules to westbound traffic, which previously applied only to eastbound traffic.

Against the background of the limited infrastructure of the Eastern polygon of Russian Railways, JSC, the development of the Northern Sea Route corridor, which is an alternative route to East Asia from the northern and central regions of Russia, could help resolve this problem.

The volume of container cargoes switched from Russia to China from other routes to deliveries via the Northern Sea Route only today amounts to about 280,000 TEUs or 4.1 million tonnes (primarily of enterprises of central and northern regions of Russia gravitating to the route) and the same scope of imports from China.

However, having a huge potential for filling the route with cargo from trade between Russia and China, the successful development of the Northern Sea Route ITC currently faces a number of obstacles in terms of the previously mentioned conditions.

The most critical is the weak technical and technological equipment of the route [2] and the impossibility of year-round navigation[29]. This results in insufficient quality of service and high cost of services, which will nevertheless be levelled out as Russia im-

[26] The graphic representation was formed by the author on the basis of data of Russian Railways, JSC and other public sources.
[27] Forecast of Social-Economic Development of the Russian Federation for 2024 and the Planned Period of 2025 and 2026 // Ministry of Economic Development of the Russian Federation. URL: https://www.economy.gov.ru/material/directions/makroec/prognozy_socialno_ekonomicheskogo_razvitiya/prognoz_socialno_ekonomicheskogo_razvitiya_rf_na_2024_god_i_na_planovyy_period_2025_i_2026_godov.html
[28] The global recovery is slowing amid widening divergences among economic sectors and regions // International Monetary Fund. URL: https://www.imf.org/en/Publications/WEO/Issues/2023/07/10/world-economic-outlook-update-july-2023
[29] Mikhailov A. In 2024 Navigation on the Northern Sea Route Will Become Year-Round // Rossiyskaya Gazeta. Economy. 17.06.2022. URL: https://rg.ru/2022/06/17/reg-szfo/v-2024-godu-sudohodstvo-na-severnom-morskom-puti-stanet-kruglogodichnym.html

plements its measures[30] and the States concerned, especially China.

At present, in the absence of non-market support mechanisms, the rate for transporting one universal large-capacity container via the Northern Sea Route exceeds the rate for a similar route via the East-West ITC by 2–2.5 times, which is a significant transport component in the price for such products as lumber and paper — the main cargo base of north-west Russia.

The solution would be to develop imports of expensive high-tech products from East Asia via the Northern Sea Route. This would allow maritime transport operators to balance their economies by shifting the cost of freight from the direction where the most sensitive to high transport costs commodity nomenclature is travelling to the direction where the cargoes are less sensitive to this, similar to the way it is currently arranged for maritime transport in communication between Europe and China (the freight rate for sending a container from Europe to China is on average 2–3 times lower than sending a container from China to Europe7). It can be assumed that companies from China are now operating under a similar scheme, setting up regular shipments of products via the Northern Sea Route[31].

Ultimately, an increase in shipments along this route will be possible after the task of reducing the cost of the sea shoulder (the share of expenses for maritime transport services along the Northern Sea Route in the comprehensive rate of the container operator is about 70–80 %) and, as a consequence, the rates of transport companies is solved.

The prospects of the North – South ITC with three routes — Western, Trans-Caspian and Eastern, to which a lot of attention has been paid recently, seem interesting.

This corridor passes through the territory of several countries (Azerbaijan, Kazakhstan, Turkmenistan, and Iran), is connected with two international corridors (Baku – Tbilisi – Kars and TRACECA), and also has access to maritime trade routes communicating with the Persian Gulf countries and India.

The western route through the Samur border crossing is the most heavily loaded at the moment, the share of its traffic in 2022 was about 85 % of all traffic along the North – South ITC, and due to a two-fold increase in volumes in January-September 2023 compared to the same period last year it reached 91 %.

The cargo base for the route is primarily the traffic in communication of Azerbaijan, Georgia and Iran with Russia and Belarus — the share of these container flows is about 95 %.

At the same time, the volume in communication with Iran is small, which can be explained by the lack of direct railway communication on the Astara (Azerbaijan) — Resht (Iran) section and the need to use road transport services.

An additional volume for the route is cargo flows between Russia and Turkey together with other countries, which follow the corridor 'Baku – Tbilisi – Kars' and TRACECA, namely through the port of Poti. Their share is the remaining 5 per cent.

It is important to note that the volume of trade of Russia and Belarus with Azerbaijan and Georgia is unbalanced for operators — only 2 % of containers can be filled with cargo, while the remaining 98 % are empty. The return of empty containers is included in the complex rate of operators for Russian companies, which allows sending expensive cargoes such as chemicals and ferrous metals, but affects the low dynamics of transportations of other nomenclature groups of cargoes and volumes of trade in containers.

In this regard, until the Astara – Resht section is commissioned, traffic volumes along the route will directly depend on containerised trade volumes between Russia and Belarus with Azerbaijan and Georgia.

The increase in traffic volumes via the Trans-Caspian and Eastern routes is developing at a slower pace due to both unprepared infrastructure32 and insufficient volume of counter cargo traffic, which does not allow for the formation of optimal logistics for operators.

The Trans-Caspian route appears to be the most optimal for the development of trade turnover between Russia and Iran, as it contains a small number of transport modalities, as evidenced by the steady increase in trade turnover along this route. Nevertheless, trade is not balanced — about 65 % of containers from Iran arriving via the Trans-Caspian route are empty.

While Russian enterprises have the potential to develop the Iranian market, shipments from this country to Russia are currently limited due to the incompatibility of the structure of the production forces of the two countries.

The main export items of both Russia and Iran are expensive but medium-sized products, including oil products, ferrous metals, plastics and products made of them. The orientation of the two countries towards supplies to East Asian countries, primarily China, has its imprint. Iran's industrial base allows it to ship small volumes of consumer goods, cars, chemical products

[30] The Order of the Government of the Russian Federation No. 2115-r dated 01.08.2022 'On Approval of the Northern Sea Route Development Plan for the Period until 2035 (as amended and supplemented).

[31] Telephones and Cars from China Travelled along the Northern Sea Route // Dvina-Inform. 01.10.2023. URL: https://www.dvinainform.ru/economy/2023/10/01/71520.html

and construction cargoes that are in demand in the Russian market. However, Russia's supply of such goods, both from its own industry and at the expense of China, does not allow for intensive development of counter trade[32].

A similar situation has also developed in transportations along the Eastern route through the Sarakhs border crossing.

When exporting in the direction of the Turkmen railway, having no return load, operators have to include in the rate the redeployment of empty fitting wagons, mainly to Kazakhstan for further shipment of containers along the Central Eurasian route of ITC 'East – West' with imports to the central regions of Russia. The cost of railway tariff for the specified empty wagon delivery by foreign railways is up to 30–40 % of the comprehensive export rate for Russian companies.

Significant growth in the volume of container transportations through the ITC 'North – South' is still observed and is caused, at least, by compliance with a number of previously noted necessary conditions:

1) ongoing work to eliminate transactions and the introduction of non-market mechanisms to stimulate transport volumes[33];

2) the availability of a major transport organiser on the route with a well-known 'brand', such as Russian Railways Logistics, JSC, and, in the future, the creation of a single operator[34].

The government's attention to the project's development and its political support play an important role.

Russia's trade imbalances with Azerbaijan, Georgia, Turkmenistan and Iran will be inevitable in the near future due to the fact that their economies are not comparable to Russia's industrial potential (*Fig. 6*).

In this regard, only a highly developed economy with a large market and industrial potential can be the most likely Russian trading partner capable of filling the North-South ITC infrastructure with the required amount of cargo. And India is such a partner.

More than 40 % of exported (in monetary terms) goods from India are containerised and potentially in demand in Russia, as evidenced by the overall trade structure of the two countries (*Table*).

At the moment, the volume of mutual trade between the two countries in containers is not at the highest levels — imports of containerised cargo account for less

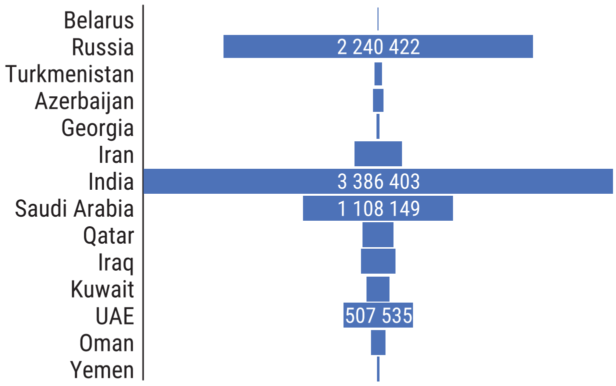

Fig. 6. Comparison of GDP of countries potentially traded using the North – South ITC in USD[35]

than 1 % of Russia's total imports, and exports to India from Russia just over 2 % of the country's exports. Nowadays, shipments mainly take place via the Southern Sea Route through the Suez Canal using the ports of Saint Petersburg and Novorossiysk and to a small extent through the ports of the Primorsky Krai.

Looking at the trade structure as a whole, Russia ranked 5th in India's imports at the end of 2022 with a share of less than 6 % (energy accounted for 84 % of all imports if this item is excluded — 26th and about 1 %), and 36th in exports and less than 1 %[32].

Therefore, the new shorter multimodal container route and the reduction of the transport component in the final price of the products of the two countries can become a significant factor in increasing trade.

A positive circumstance is the interest of the Indian business community in developing trade through the North-South ITC. In addition, India is interested in developing transit flows along the corridor towards Europe. The main focus is on the route using the port of Chabahar, which is the only deep-water port in Iran[36]. In addition to solving the tasks of creating acceptable price conditions and removing infrastructure barriers to the development of transit to Europe from India, there is a high probability of low volumes of counter cargo traffic from Europe to India against the backdrop of sanctions against Russia, which will only exacerbate the current unfavourable situation for operators with a surplus of equipment in the western part of Russia.

[32] Trade Map. URL: https://www.trademap.org/Index.aspx

[33] *Lobko V.* Through Service and Through Tariff. From 2023, Container Transportations along the North-South Corridor Will Become Even More Favourable for Consignors // Gudok. 30.11.2022. URL: https://www.gudok.ru/content/freighttrans/1621132/

[34] *Skorlygina N.* North — South Will Figure it out for Three. Russia, Azerbaijan and Iran May Create a Single Logistics Operator // Kommersant. No. 202/P dated 31.10.2022. P. 7. URL: https://www.kommersant.ru/doc/5644946

[35] GDP — Gross Domestic Product // countryeconomy.com URL: https://countryeconomy.com/gdp

[36] *Skorlygina N.* A Track to the Big Game. What Russia's Partners in the North-South Corridor Care about // Kommersant. 09.06.2023. URL: https://company.rzd.ru/ru/9401/page/78314?id=210095

Table

Structure of Russia's Imports and India's Exports in Monetary Terms[32]

List of items	Russia's imports from all countries (2021), %	Exports to all countries from India (1 half-year 2023), %
Machinery and mechanical equipment	19	6
Electrical machinery and equipment	13	7
Transport vehicles	9	5
Pharmaceuticals	5	5
Plastics and plastics products	4	2
Optical and measuring instruments	3	1
Iron or steel products	2	2
Organic chemicals	2	5
Furniture and accessories	1	1
Rubber and rubber products	2	1
Essential oils and rubbers, perfumes	1	1
Clothing and clothing accessories	3	4
Other chemicals	1	2
Inorganic chemicals	1	1
Ships, boats, etc.	2	1
Footwear	1	1
Paper and cardboard; articles made of paper pulp, paper or cardboard	1	1
Fish and crustaceans	1	1
Oil seeds and oily fruits	1	1
Tannin or colouring extracts, dyes	1	1
Other	28	54

In view of the largely commodity-based structure of the Gulf economies[38] the development of transport in the coming years will potentially be possible only in the export direction from Russia, and therefore the development of logistics through the North-South ITC with these countries will inevitably face the problems typical for the countries of the Transcaucasus and Iran — the lack of sufficient back-loading and the resulting high cost of transport costs for Russian shippers.

CONCLUSIONS

The dramatic growth of the East-West ITC was possible solely due to subsidies and political will of China, and this experience of creating favourable conditions seems to have little transferability to other corridors.

The East – West ITC will continue to be a key corridor for Russia in the near term, and therefore it should receive the most attention from the government and transport industry players in terms of technical and technological development.

The Northern Sea Route can become a complement to the East – West route, but only if many technically challenging tasks are solved to reduce freight costs. As practice has shown, the establishment of regular container shipments along the route is economically feasible for high value-added cargoes under conditions of cost compensation (actually subsidisation) for counter cargo traffic with inexpensive cargoes.

No matter how significant the plans to expand the infrastructure of the North –South ITC are, the development of economic and industrial relations between the countries it links should remain ahead of the rest. Without a balance of mutual cargo flows, the optimal transport logistics for container operators and the costs of these logistics for their customers will not be formed.

The solution to these issues will be the development of complex industrial globalisation projects in the contour of Eurasia, allowing to use the strong geographical, scientific-industrial and social sides of one or another country. Another option could be the creation of large logistics hubs, for example, on the borders of Azerbaijan and Turkmenistan with Iran, where cargoes will be consolidated for further shipment by regular container trains on the 1,520 mm gauge.

The establishment of large volumes of trade between Russia and India, which will be crucial to the future success of the North – South ITC project, has significant and undiscovered potential.

For all countries involved in freight transport along the above-mentioned corridors, the key issues for the next few years will remain the issues of infrastructure development and significant investment both in this construction and in the industrial potential of their own economies. Not to mention the elimination of barriers in the so-called 'soft' infrastructure of ITC (across-the-board tariffs and coordinated tariff policy independent of currency fluctuations, settlement and insurance mechanisms, digitalisation and automation of processes, etc.).

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The Donetsk Railway Transport Institute: yesterday, today, tomorrow

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Обзорная статья

Донецкий институт железнодорожного транспорта: вчера, сегодня, завтра

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INTRODUCTION

The Donetsk Railway Transport Institute (DonIZhT) was founded on 3 November 1967 as a training and consulting centre of the Kharkov Institute of Railway Engineers (Order of the USSR Minister of Railways No. E-29415). On 1 January 1968, in order to improve the quality of training of engineers for Donetsk Railways, the training and consulting centre was transformed into the Donetsk Branch of the Kharkov Institute of Railway Engineers.

The Donetsk Railway Transport Institute owes its creation to high levels of freight traffic and shortage of staff on Donetsk Railways. Executives of the Ministry of Transport of the USSR tried to resolve the shortage of engineering personnel through a distance learning system, where more than a thousand employees of Donetsk Railways and transport departments of industrial enterprises studied by correspondence in railway transport institutes and at technical faculties of other higher education institutions. However, at that time higher education institutions had limited capabilities and the implementation of educational programmes was complicated because of their remoteness from where distance students resided. This inspired the management of Donetsk Railways to establish the Donetsk branch of the Kharkov Institute of Railway Engineers — the idea was supported by the Head of Donetsk Railways Viktor Priklonsky. Chief executives of Donetsk Railways proposed to appoint the Head of Engineering Works of the Permanent Way Department of their Railway Administration Nikolai M. Tseluyevsky as Director of the Branch and M.P. Gavrichkov was appointed Deputy Director for Academic Work.

All of the key functions and departments of Donetsk Railways were assigned to provide practical support to the Branch in creating laboratories and study rooms. Thus, the Wagon Service Department of the Railway Administration created a study room for analytical mechanics; the Electrification and Power Utilities Department set up an electrical engineering laboratory; the Signalling and Communications Department organized a laboratory of physics, linear electrical circuits, signalling and communications; and the Medical and Sanitary Department equipped a chemistry laboratory. The Permanent Way, Locomotive Facilities and Logistics Departments provided invaluable assistance to the Branch, too.

In 1971, the Branch began to carry out contract-based research and development projects. It has completed an R&D project to design and build a set of programmes for calculating technical standards for the operational work of Donetsk Railways and its departments with the use of ES EVM computers. The outcome of this effort was put into practice in 1984–1986. The Branch has also developed an installation and technology for build-up welding of frogs in a pulsed magnetic field. The technology was used to restore about 200 frogs on heavy traffic lines of Donetsk Railways. The wear resistance of the restored frogs turned out to be 1.3 times higher than that of the existing ones.

Early in its history, the Institute only had distance students. Intramural training of engineers at the Donetsk Branch of the Kharkov Institute of Railway Engineers was launched in 1991. Daytime studies were made possible thanks to major preparation efforts made by academic and administrative staff of the Branch with the support of academic departments of the Institute and functions of Donetsk Railways.

In 1996, the Donetsk Branch acquired the status of an institute as a division of the Kharkov State Academy of Railway Transport. Highly intense competition for enrolment in the first year of studies showed that young people of Donbass were ready to cast their lot with railway transport. In the early 2000s, the Donetsk Railway Transport Institute ranked third in terms of the number of candidates competing for enrolment among 18 state higher education institutions in the region.

The Institute built and improved its structure. In general, it has taken a form that is standard for universities with level 3 and 4 accreditation. The Institute's first daytime faculty was named "Railway Transport Management". Two other faculties, Railway Transport Infrastructure and Economics of Transport, were formed out of it in 1998 and 2001, respectively. The Faculty of Extramural Studies managed the training process for distance students, as it did during the early years of the Branch.

1998 saw change in the executive team of the Institute. Professor Vladimir I. Poddubnyak, PhD in Engineering, who earlier served as Vice-Rector for Academic Affairs, became Rector of the Donetsk Railway Transport Institute.

In 1998, the Advanced Training Faculty was established, and its facilities were used for the operation of an expertise centre for occupational health and safety of the Ministry of Transport.

The success of the Institute's team in achieving its goals was recognized by Order of the Cabinet of Ministers of Ukraine No. 575r dated 11 October 2002 "On the Establishment of the Donetsk Railway Transport Institute of the Ukrainian State Academy of Railway Transport", which instituted it as a state higher educational institution with the rights of a legal entity. This formed a basis for subsequent Order of the Ministry of Transport of Ukraine No. 807 dated 12 November 2002.

In accordance with the Decree of the Council of Ministers of the Donetsk People's Republic No. 35-10 dated 26 September 2014, the Institute was moved under the control of the Ministry of Education and Science of the Donetsk People's Republic.

Order of the Government of the Russian Federation No. 750-r dated 29 March 2023 established federal ownership of the Russian Federation over the Donetsk Railway Transport Institute in the form of state budgetary educational institution of higher education.

As of 2023, the Institute has two faculties, one branch for secondary vocational education, and the Continuing Education Centre.

MISSION OF THE DONETSK RAILWAY TRANSPORT INSTITUTE

The Donetsk Railway Transport Institute is the leading educational institution in the field of transport in the region, engaged in both academic and research activities. The Institute provides training in higher education (bachelor's, specialist's, master's, and postgraduate programmes) in 13 specialties (areas of training); in secondary vocational education (training programmes for mid-level specialists) in 5 specialties; and in vocational training and additional education programmes.

One of the key success factors of the Donetsk Railway Transport Institute is its close cooperation with the leading employer in the region's transport industry, Railways of Novorossiya Federal State Unitary Enterprise. Through this cooperation the Institute is aware of current requirements and trends in the industry and can provide its students with opportunities for practical training and further employment. The Institute also serves as a forum for meaningful interactions with authorities, business, science and education communities by hosting scientific conferences and contributing to the development of expertise programmes for the development of the transport industry in the Donetsk People's Republic.

The high quality of training of engineers provided by the Donetsk Railway Transport Institute is attested by the fact that its graduates are highly sought after on the labour market. Many graduates begin their career on the Donetsk railways and other regional railways, as well as at industrial transport enterprises. This shows the confidence placed in the Institute by employers and supports its reputation as a provider of highly skilled professionals.

Results of R&D activities undertaken by the Institute's academic departments, and materials of dissertation research performed by postgraduate and doctoral students are actively introduced in the training process and used to create simulators and benches for laboratory and hands-on classes.

The main areas of R&D activities at the Donetsk Railway Transport Institute include:

1. Development of control systems for railway transport using artificial intelligence methods and tools.

2. Improvement of the technology for laying continuous welded track and structural components of the track superstructure.

3. Managing operation of transport systems and transport and logistics systems, and optimization of their certain elements.

4. Feasibility evaluation and development of compact cooling systems with high heat dissipation capacity for power equipment of traction rolling stock.

5. Development of new aerodynamic designs and configurations for energy-efficient axial motor fans for cooling devices in diesel locomotives.

The Institute's strategic goal for the period until 2030 is to achieve the status of a higher educational institution that makes a major theoretical and practical contribution to the innovative development and overall competitiveness of the transport industry of the Russian Federation. The development of the Donetsk Railway Transport Institute is aimed at catering for the needs of Railways of Novorossiya for competent employees with higher and secondary vocational education. The Institute keeps an eye on the latest trends and progress in the field of transport and provides its students with up-to-date knowledge and skills to enable them to build a successful career in the dynamic transport industry. The Donetsk Railway Transport Institute strives to provide the transport industry with highly skilled professionals by making available an optimal environment for training, retraining and advanced training. Moreover, the Donetsk Railway Transport Institute engages in research and development with the view to improve the performance and competitiveness of railway companies.

To achieve its goal, the Institute pursues a number of objectives. The measures taken by the Institute to improve the efficiency of its educational activities involve the introduction of educational innovations at all levels and for all types of education. This approach will help establish a more interactive and attractive learning environment where students can be actively involved in the educational process. It also plans to digitalize all the processes at all decision-making levels, automate administrative tasks, and improve communications between participants of the educational process. One of the priority objectives is to implement systemic update and modernization of the educational simulators, educational laboratory equipment, and laboratory facilities used in R&D activities. This will help improve the practical focus and effectiveness of R&D activities, expand the areas of research work and the range of scientific services, and make them more relevant.

The Institute develops special programmes and activities designed to reveal and develop talents among students. It offers an environment for successful study and professional growth of gifted students. It is planned to provide special training for graduates to support them in undergoing the assessment of corporate and professional competencies at Russian Railways OJSC. This will increase competitiveness of graduates from the Donetsk Railway Transport Institute and enable them to successfully complete any evaluation of their knowledge and skills.

It is planned to implement comprehensive activities to develop scientific potential, create favourable conditions for R&D efforts, actively support scientific projects and programmes, and attract highly skilled scholars and experienced professionals for cooperation and exchange of experience.

The Donetsk Railway Transport Institute continuously adapts the range of its educational services to meet changing needs of the labour market in the industry and economy of the region at all levels and for all types of education. The Institute works to ensure that the qualification of its teaching staff, educators, researchers, administrators, managerial and support staff is confirmed and upgraded in a systematic and timely fashion.

One of the important areas of focus in the Donetsk Railway Transport Institute is not only to develop students' professional skills but also to contribute to their personal qualities, create an educational environment that promotes the development of their general cultural and professional competencies, patriotic awareness, and social activism. The Institute intends to invite outstanding scholars and experienced practical workers to join its educational activities. This will give students opportunities for learning knowledge and experience from cutting-edge industry representatives and expanding the range of their professional contacts and career prospects.

In order to contribute to the social and economic development of the Donetsk People's Republic, the Donetsk Railway Transport Institute engages in activities in the following areas:

1. Building effective partnerships with local schools with the view to establish a system of profession-oriented education in the region: facilitation of information transparency of the student enrolment process, presentation of new, practice-oriented educational programmes, and promotion of employment practices at promising enterprises and strategic sites for graduates from the Donetsk Railway Transport Institute. Company-sponsored education and involvement of employers and regional executive authorities in career guidance counselling are important factors of the project success. Career guidance counselling in schools, vocational schools and colleges, including information meetings, profession-specific classes, meetings with key partners of the Donetsk Railway Transport Institute, dissemination of information materials with a focus on relevant areas — all these are important for the creation of a successful system of profession-oriented education.

2. Modern requirements and challenges in various sectors of the economy require that the content of the training programmes offered by the Institute be upgraded and their range be expanded. It is planned to adjust the package of competencies in collaboration with industrial partners, optimize the number of and allocate contact work hours to practical work at enterprises, and to build the training process with a focus on industry-specific courses.

Students at classes in the laboratory of the Railway Rolling Stock Department. Training simulator: High-voltage cabinet and control console of 2TE116 diesel locomotive

3. Building a system for the involvement of employees of the Donetsk Railway Transport Institute in profession-specific programmes of advanced training for the benefits of companies and enterprises in the Donetsk People's Republic. This will enable the Institute to be abreast of the latest trends and inventions in the industry, better prepare students for meeting the requirements of regional companies and enterprises, and build a more balanced link between education and the labour market.

4. Upgrading of the laboratory facilities in the educational divisions that are involved in the development of key areas of the regional economy, social and cultural sphere in the Donetsk People's Republic is necessary in order to ensure that students develop practical skills in working with modern equipment and technologies that are utilised by important sectors of the industry of the region and to develop their professional skills and train competitive professionals for strategic sites in the Donetsk People's Republic.

Higher education organisations influence the achievement of national development goals of the Russian Federation by acting as key providers of workforce for the economy and implementing research and development projects that contribute to the country's technological development. The Donetsk Railway Transport Institute consistently focuses its areas of activity on the achievement of the national goals and strategic objectives for the development of the Russian Federation.

To achieve these goals and given the capabilities available to the Donetsk Railway Transport Institute, its scientific and academic work will be focused on the following priorities, which will provide a framework for building links between educational programmes, scientific schools, and the transport sector of the Russian economy:

- opportunities for self-realisation and talent development;
- digital transformation.

The activities of the Donetsk Railway Transport Institute are aimed at solving the following tasks to contribute to the achievement of the national development goals:

1) development of an effective system to discover, support and nurture talents and abilities in children and young people based on the principles of justice and universal access aimed at promoting self-determination and occupational guidance of students; holding of contests, academic competitions, festivals and other activities to discover and support gifted children and young people;

2) creation of conditions for the development of a harmoniously developed and socially responsibility personality on the basis of spiritual and moral values of the Russian Federation, historical and cultural values; conducting educational work to develop patriotism, civic mindedness, and respect for human rights and moral values in students;

3) achievement of digital maturity of education and creation of a modern and safe digital educational environment that will provide high quality and accessibility of education of all types and levels and ensure training of digitally competent workforce;

4) upgrading of professional education by introducing adaptive, practice-oriented and flexible educational programmes designed to train professionals with skills required by the labour market;

5) creation of a system for continuous professional knowledge update and acquisition of new skills by employed individuals, including the development of competencies in digital economy, by providing advanced training and retraining opportunities and developing distance education;

6) creation of an environment for the development of a mentorship system, the support of students' self-governance and youth initiatives, including in the field of volunteering.

CONCLUSION

The mission of the Donetsk Railway Transport Institute is to train highly skilled professionals for work in railway transport. The Institute strives to provide students with high-quality education, develop research, and promote innovation and technology progress in the railway transport sector. It also works to strengthen ties between industry and business so that its graduates can enjoy the best possible employment and career opportunities.

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