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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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# СОДЕРЖАНИЕ

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# International railway fair in the area 1520 "PRO//Motion.Expo"*

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ABSTRACT The article reviews the framework work of the International Salon "PRO//Motion.Expo-2025", held on August 28–31, 2025 in St. Petersburg in Russian Railway Museum and Baltiyskiy railway station. The event, organized by JSC Russian Railways every two years, has become a key platform for demonstrating the achievements of domestic and foreign railway engineering.

The salon program included "Business Days" (August 28–29) and "Open Road Days" (August 30–31) with workshops, lectures and an exhibitions of equipment. Over 130 companies, including JSC Transmashholding, JSC Sinara — Transport Machines, NPC United Wagon Company and foreign companies from China and CIS countries, presented their developments on an area of over 5,000 m$^2$. High–speed highways were especially important in the discussions: educational programs for training 500 specialists by 2028 was announced, and infrastructure solutions for the Moscow – St. Petersburg high-speed railway were presented. Emperor Alexander I Petersburg State Transport University demonstrated robotic platforms and interactive simulators. Treaties were signed, panel discussions on technological sovereignty and digitalization were held, and a dynamic exposition of historical rolling stock dedicated to the 80th anniversary of the Victory in the Great Patriotic War was presented. The railway fair confirmed the status of the largest exhibition in the 1520 railway zone.

KEYWORDS: "PRO//Motion.Expo"; JSC Russian Railways; HSR (high-speed railway); railway engineering; robotic platforms; digitalization; personnel training; international treaties

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*Заметка*

# Международный салон «PRO//Движение.Экспо» 2025*

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АННОТАЦИЯ Освещена работа Международного салона «PRO//Движение.Экспо-2025», прошедший 28–31 августа 2025 г. в Санкт-Петербурге в Музее железных дорог России и на станции Санкт-Петербург Балтийский. Мероприятие, организуемое ОАО «РЖД» один раз в два года, стало ключевой площадкой для демонстрации достижений отечественного и зарубежного железнодорожного машиностроения.

Программа салона включала «Деловые дни» (28–29 августа) и «Дни открытых дорог» (30–31 августа) с мастер-классами, лекциями и выставкой техники. На площади свыше 5000 м2 представили разработки свыше 130 компаний, включая АО «Трансмашхолдинг», Группу «Синара», НПК «ОВК» и зарубежные фирмы из Китая и стран СНГ. Центральное место в обсуждениях заняла тема высокоскоростных магистралей: анонсирован запуск образовательных программ для подготовки 500 специалистов к 2028 г., представлены инфраструктурные решения для ВСМ Москва – Санкт-Петербург. ПГУПС продемонстрировал роботизированные платформы и интерактивные тренажеры. Также состоялись подписания соглашений, панельные дискуссии о технологическом суверенитете и цифровизации, динамическая экспозиция исторического подвижного состава к 80-летию Победы. Салон подтвердил статус крупнейшей выставки в зоне железных дорог 1520.

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КЛЮЧЕВЫЕ СЛОВА: «PRO//Движение.Экспо»; ОАО «РЖД»; ВСМ (высокоскоростная магистраль); железнодорожное машиностроение; роботизированные платформы; цифровизация; подготовка кадров; международные соглашения

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On August 28–31, 2025, the international railway fair "PRO//Motion.Expo" was held in St. Petersburg. JSC Russian Railways traditionally organizes it every two years. These forums are railway exhibitions, and, starting in 2019, they were held on experimental ring territory of the JSC Railway Research Institute (JSC "VNIIZHT") at Shcherbinka station near Moscow. Since 2023, the railway fairs "PRO// Motion.Expo" are held in St. Petersburg at the Museum of Russian Railways and on the tracks of the St. Petersburg Baltiysky railway station.

The 2025 international railway fair was attended by Oleg Belozerov, General Director and Chairman of the Management Board of JSC Russian Railways, Alexey Shilo, Deputy Minister of Transport of the Russian Federation, Kirill Polyakov, Vice Governor of St. Petersburg, Valery Tanaev, Deputy General Director and Chief Engineer of JSC Russian Railways, Sergey Saratov, Deputy General Directors of JSC Russian Railways and Evgeny Charkin, Rector of Emperor Alexander I Petersburg State Transport University Oleg Valinsky, Rector of Volga Region State Transport University Maxim Garanin, Rector of Irkutsk State Transport University Yuri Trofimov, Head of the Technical Policy Department of JSC Russian Railways Vladimir Andreev, General Director of JSC Transmashholding Kirill Lipa, General Director of JSC Sinara — Transport Machines Viktor Lesh, Director of SPB GUP GorElectroTrans Denis Minkin, Head of State Unitary Enterprise St. Petersburg Metro Evgeny Kozin and other officials.

Back in August 1845, the first batch of steam locomotives was produced in Russia for the railway between St. Petersburg and Moscow. Exactly 180 years later, from August 28 to 31, the St. Petersburg Museum of Russian Railways hosted the International Railway Salon "PRO//Motion.Expo". It celebrated the achievements of Russian railway engineering, including the production of locomotives.

The railway fair program was divided into two parts: "Business Days" and "Open Road Days". The first one took place on August 28 and 29. On August 30 and 31, the general public was allowed to visit the railway fair — guests could attend workshops, thematic lectures and an exhibition of ancient railway techniques.

General view of the open exhibition area of the railway fair "PRO//Motion.Expo" 2025.
Photo by Arkady Shapovalov, JSC Russian Railways Press Service


Railway fair "PRO//Motion.Expo" 2025.
The stand of JSC Firma Tvema.
Photo from Photobank of JSC Gudok Publishing House


Railway fair "PRO//Motion.Expo" 2025.
The stand of the Chinese electrotechnical company Zhejiang Yonggui Electric.
Photo from Photobank of JSC Gudok Publishing House

About 70 samples of modern and rare railway equipment were demonstrated at the Museum of Russian Railways as a part of the railway fair. About 130 exhibiting companies, including foreign ones, presented their stands on an area of more than 5,000 m$^2$. Among these are JSC Russian Railways and the flagships of the Russian and global railway engineering: JSC Transmashholding, PTK Group, JSC Sinara — Transport Machines, NPC United Wagon Company, JSC Natsproektstroy, JSC Firma Tvema, JSC RPC INFOTRANS, JSC Research and Design Institute for Information Technology, Automation and Communication in Railway Transport, JSC Radioavionika and other large manufacturing and technological enterprises from Russia, China and the CIS countries. Railway-profiled universities also presented their achievements at the exhibition.

High-speed rail traffic is a key direction in the development of our country's land transport. Oleg Belozerov, General Director and Chairman of the Management Board of JSC Russian Railways, and Alexey Shilo, Deputy Minister of Transport, discussed this in detail in their speeches.

To date, 23 regulations on the construction and operation of the high-speed railway have been adopted. They cover the rules of technical operation, requirements for rolling stock, rights and obligations of infrastructure operators, etc. Basically, legislation for highways with speeds exceeding 300 km/h is being adopted. The concept of HSR is official in Russian Federation with a law that came into force on September 1, 2025.

This year has really been breakthrough for the HSR sector — the implementation of the highway project between the two main cities of the country has begun. The Moscow—St. Petersburg high-speed railway has become the most important topic of discussion at the salon as a priority national project. Ballast-free plates


The meeting devoted to the issues of high-speed rail traffic, held under the motto: "High-speed rail in Russia: transition to a new technological order. The challenges for the industry are the potential for the country". General Director and Chairman of the Management Board of JSC Russian Railways, O.V. Belozerov, takes the floor. August 29, 2025
Photo Photobank of JSC Gudok Publishing House

A model of a Russian high-speed electric train
for the Moscow–Saint Petersburg high-speed railway.
Photo from Photobank of JSC Gudok Publishing House

and other road and infrastructure solutions applicable to high-speed railways were demonstrated. Chinese colleagues also "see the potential in the high-speed highway space as a market for high speeds and innovative components" and expressed a desire to assist in the implementation of the ambitious project of the Russian Federation. For example, Chinese partner companies Sinomac and RailMac (they demonstrated their traction equipment, battery system and digital solutions during the railway fair), showed interest in the 1520 market and their solutions adaptation to Russian conditions, such as cold climate.

The past has not been forgotten either. Thus, the ROLLINGSTOCK Agency prepared a magazine with a review of the "World of High-speed Trains" specifically for the railway fair. It presented a kind of retrospective of the HSR from the 1960s to 2025.

HSR is not only a transport project, but also a system platform. It requires simultaneous standards development, technical and digital solutions adoption, and, finally, personnel training. In this regard, the Ministry of Transport announced new educational programs: first engineers of the relevant profile are expected to graduate in 2 years, and by 2028 at least 500 specialists should be trained. The panel discussion for discussing these complex tasks was established in PRO//Motion. PRO//Education. Research Bridge", held within the framework of the International railway fair "PRO//Mo-

Concrete slab of ballast–free contracting of the Moscow – Saint Petersburg HSR route.
Photo from Photobank of JSC Gudok Publishing House

Participants of "Research Bridge" panel discussion. Photo by Daria Korshunova

"Research Bridge" panel discussion. Oleg Valinsky, an expert of the panel and rector of the Emperor Alexander I Petersburg State Transport University is speaking. Photo by Daria Korshunova

tion.Expo" August 28, 2025 The key question is whether the education system is ready for the challenges of the HSR and how universities should transform in order to train specialists not only for current needs, but also for 2030+ technologies. Young researchers from Emperor Alexander I Petersburg State Transport University, Russian University of Transport, Irkutsk State Transport University, Volga State Transport University, Ural State University of Railway Transport.

The experts were Sergey Saratov, Deputy General Director of JSC Russian Railways, Evgeny Charkin, Deputy General Director of JSC Russian Railways, Vladimir Andreev, Head of the Technical Policy Department of JSC Russian Railways, Oleg Valinsky, Rector of Emperor Alexander I Petersburg State Transport University, Viktor Lesh, General Director JSC Sinara — Transport Machines, Maxim Garanin, Rector of Volga State Transport University, Yuri Trofimov, Vice-Rector of Ural State University of Railway Transport Oleg Balagin, Director of the Advanced Engineering School "VSM Academy AES" in Russian University of Transport Oleg Pokusaev. Together with the participants, they discussed if the education system is ready for the challenges of high-speed transport, as well as what, from the point of view of customers — key industrial partners of universities — should be the training program for high-speed communication. The issue of competencies students should have and requirements needed to launch the program was also raised.

"The focus is now on personnel training for the HSR. In order to succeed, we need different specialties and jobs, from workers to managers and engineers. Therefore, we work systematically in three areas of personnel training: working personnel — in technical schools, The Russian University of Transport and the Emperor Alexander I Petersburg State Transport University, management engineers — in the HSR Academy and ISKRA ("Integrated System of integrated distributed architecture") Advanced Engineering School. The JSC Russian Railways Corporate University will train current employees. The roadmap has been developed accordingly, and we are carefully following the points and deadlines in it. We are confident that we will be prepared for the launch of the HSR in terms of personnel for operating and managing the vehicles", Sergey Saratov, Deputy General Director of JSC Russian Railways, said.

We have fewer and fewer design engineers. We are in need of engineers who understand the technology. Systems engineers that already know how mechanisms work. And the technologies should be breakthrough, meaning it's pointless to waste research resources on something that someone else has been trying to create for a long time. Moreover, we have to formulate the task of these breakthrough technologies ourselves", Viktor Lesh, General Director of JSC Sinara — Transport Machines, declared.

Denis Kravchenko, moderator of the discussion and Editor-in-Chief of JSC Gudok Publishing House, while summing up the results, stressed that the forum turned out to be eventful and informative. Young researchers, together with front-line experts, have created an incredible symbiosis of science and practice. He thanked the young researchers and representatives of specialized universities for their presentations and projects, and also highlighted the contribution of experts who created the very research bridge between real production and science.

The St. Petersburg – Moscow high-speed railway is scheduled to be commissioned in 2028, and Denis Kravchenko expressed confidence that transport universities are keeping the situation under control and making efforts to successfully implement this large-scale project.

The St. Petersburg State University of Railways of Emperor Alexander I presented its developments at the exhibition: robotic platforms for the inspection of metal structures and industrial facilities, as well as interactive laboratory installations and 3D atlases.

The robotic inspection platform for metal structures was developed jointly by the staff of the Department of "Ground Transport and Technological Complexes" of Emperor Alexander I Petersburg State Transport University and LLC Robocont within the framework

The unmanned platform on a combined course "Sputnik-ZhD" (Sputnik railway platform) that was developed by specialists from Emperor Alexander I Petersburg State Transport University's Department of "Ground transport and Technological Complexes". Photo by Tatiana Arzamastseva

of the strategic academic leadership federal program "Priority-2030".

The device helps with diagnosing the technical condition of gantry cranes, overhead cranes and supporting elements of various structures. The robot is able to move under metal structures and overcome 90-degree bends along box-shaped beams.

Another robotic platform, RASTRUB, is designed for internal inspection of extended industrial facilities and pipelines with nominal diameters of 500–1200 mm. The device provides high-precision monitoring on long sections of highways.

The platforms are equipped with modern navigation tools and data collection systems, which makes them effective for monitoring the infrastructure and preventing emergencies.

The unmanned platform on a combined course "Sputnik-ZhD" (Sputnik railway platform) was developed by specialists from Emperor Alexander I Petersburg State Transport University's Department of "Ground transport and Technological Complexes". The prototype was created at the end of 2024. The design and elements of the combined stroke were manufactured at the Experimental Plant of the Oktyabrskaya Railway — Branch of JSC Russian Railways. It can be used to transport work crews, track mechanized tools, materials for high-speed trains, ultrasonic and magnetic monitoring of railway condition. When connecting several platforms, 12.5 m and 25 m rails can be transported.

It is convenient to use such self-propelled rolling stock, first of all, on low-intensity lines, as well as during repair work on closed tracks. The platform can move off the track on stages without any additional devices and devices and independently enter the rails. The movement of the device is provided by four traction electric motors powered by a high-power lithium battery. With a mass of about 1 ton, the platform can take the same load.

The digital technologies developed by Emperor Alexander I Petersburg State Transport University researchers aroused the keen interest of the transport industry specialists during the exhibition. For example, the University Branch Research Laboratory (ONIL) "Automation of maintenance, diagnostics and monitoring of harvester systems" showed interactive simulators and training manuals for builders, construction workers, wagon workers and track workers.

Simulators are, in fact, interactive 3D models that open up a lot of learning opportunities. Thus, the laboratory installation "Design and installation of a culvert" allows you to get acquainted with the stages of laying communications, as well as to understand what equipment and equipment are necessary for the safe performance of work. The Signaling relay equipment installation is designed to study the maintenance and components of electromagnetic relays. 3D atlases of freight wagons and railway tracks help to study the design of rolling stock and tracks, and then check how much knowledge has been acquired. At the same time, you can examine the device in detail, even see what is hidden for visual inspection.

It is also worth-noting how relations with foreign colleagues were strengthened during the "Business Days" of the forum. The exhibition is believed to be the largest in the 1520 railway zone (Russia + CIS) with the participation of foreign companies. Both Asian and European delegations participated. In total, seven agreements were signed, including one concerning co-operation between JSC Russian Railways and the State Association "Belarusian Railway".

The guests from China also presented the latest developments and expressed their opinion about the exhibits presented at the forum. "Over the four-day exhibition, exhibitors showcased cutting-edge technologies and innovative achievements in the railway transportation industry", Chinese edition of Emac wrote, noting the high level of the event and the productivity of discussions[1].

"PRO//Motion.The Expo" discussed the prospects for the development of railway engineering, especially in a multipolar world. Other issues highlighted were

[1] https://ccec-engine.com/deeply-cultivate-the-international-market-empowering-the-future-of-rail-focus-pro-motion-expo-2025-sinomac-exhibition-highlights-review/


The newest Russian locomotives and wagons: In the photo from left to right: a two-section multifunctional diesel vehicle of the Pioneer-Integral project, designed to diagnose infrastructure devices, by JSC Firma Tvema; EP2M suburban DC electric train by Demikhovo Machine-Building Plant; two-section electric locomotive with asynchronous traction electric motors 2TE35A by JSC Sinara – Transport Machines; main cargo electric locomotive of alternating current 2ES11 "Orlets" with asynchronous traction drive by Ural Locomotives LLC. Photo Photobank of JSC Gudok Publishing House

Retro equipment exhibition. A unique steam locomotive of the OP 7587 series, produced in 1907 at the Putilov Plant in St. Petersburg. August 29, 2025.
Photo Photobank of JSC Gudok Publishing House


Retro equipment exhibition.
The steam locomotive of the FD20-1675 series, produced in 1937 by October Revolution Voroshilovgrad Diesel Locomotive Construction Works. August 29, 2025.
Photo Photobank of JSC Gudok Publishing House

Theatrical performance "Victory" at the site of Russian Railway Museum. August 29, 2025. Retro equipment exhibition.
A unique steam locomotive of the OP 7587 series, produced in 1907 at the Putilov plant in St. Petersburg.
Photo Photobank of JSC Gudok Publishing House

the conditions for achieving Russia's technological sovereignty and mutually beneficial cooperation, as well as the introduction of new technologies, such as domestic production of locomotives, digitalization and unmanned transport systems. Unique domestic developments were presented during the event. Among them are specialized freight wagons, modern "smart" locomotives, updated first-class carriages and the latest T-size wagon for passenger transportation.

At the end of the railway fair, a dynamic exposition of historical rolling stock was presented. It was dedicated to the 80th anniversary of the Great Victory and the 180th anniversary of the Russian locomotive industry. 11 steam locomotives passed through the tracks of the Baltic Railway Station.

The program ended with a theatrical performance recreating the the return of soldiers from the Great Patriotic War and the Victory celebration.

## Bionotes

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# Managing innovation in corporations: The experience of JSC Russian Railways*

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ABSTRACT This paper examines the innovation management system at Russian Railways (RZD), one of the largest railway companies in the world, and analyses the evolution of the RZD innovation policy from 2007 — the year that a strategic course for technological development was taken — up to the present day.

In the paper the authors describe the key institutional element of the system: the Center for Innovative Development (established in 2009), which coordinates strategic planning, methodological supporting, the management of the external projects portfolio, interacting with the external environment, and intellectual capital. We also show how the company moved from isolated experiments to a centralized management system that oversees its central and regional levels, as well as subsidiaries.

The paper introduces the main forecasting and planning tools used: foresights (including a long-term, foresight study up to 2050 completed in 2021) and technological comparisons (benchmarking against 60 foreign companies according to 70 individual metrics and 34 technological areas). The authors give examples of innovative projects that are being implemented: driverless trains on the Moscow Central Circle; a digital railway station in Chelyabinsk; and the construction of the high-speed railway between Moscow and St. Petersburg.

Further, we describe the "open innovations" ecosystem: regional centres for innovative development; the "One Stop Shop for Innovations" digital platform; and partnerships with technology parks and innovation clusters (Skolkovo, Innopolis, etc.). The mechanisms for supporting projects at all stages are explained — from idea (quantoriums, business incubators, and the "New Link" and JSC RZD "Idea" competitions) to replication (the Russian Railways Innovation Support Programme).

Particular attention is paid to intellectual property management: the portfolio of JSC Russian Railways includes more than 4700 assets (software, inventions, utility models, trademarks). Measures to protect intellectual property, litigation work, and commercialization strategy are discussed.

The authors conclude that a systemic innovation policy, coupled with the synergy of internal and external resources, a focus on technological sovereignty and intellectual capital management, will ensure that Russian Railways maintains its position as a transport industry leader.

KEYWORDS: innovation; JSC RZD; innovation management; innovative ecosystem; foresight; benchmarking; open innovation; intellectual property; technological development; regional centres for innovative development; digital platform; technological sovereignty

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*Обзорная статья*

# Управление инновациями в корпорациях: опыт компании «Российские железные дороги»*

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АННОТАЦИЯ Рассмотрена система управления инновациями в ОАО «РЖД» — одной из крупнейших железнодорожных компаний мира. Проанализирована эволюция инновационной политики компании с 2007 г., когда был взят стратегический курс на технологическое развитие, и до настоящего времени.

Описан ключевой институциональный элемент системы — Центр инновационного развития (создан в 2009 г.), координирующий стратегическое планирование, методологическую поддержку, управление портфелем внешних проектов, взаимодействие с внешней средой и интеллектуальным капиталом. Показано, как компания перешла от точечных экспериментов к централизованной системе управления инновациями, охватывающей центральный и региональный уровни, а также дочерние общества.

Раскрыты основные инструменты прогнозирования и планирования: форсайты (в том числе долгосрочный форсайт до 2050 г., проведенный в 2021 г.) и технологические сопоставления (бенчмаркинг с 60 зарубежными компаниями по 70 показателям и 34 технологическим направлениям). Приведены примеры реализованных инновационных проектов: беспилотное движение на Московском центральном кольце, цифровая железнодорожная станция в Челябинске, строительство высокоскоростной магистрали Москва – Санкт-Петербург.

Охарактеризована экосистема «открытых инноваций»: региональные центры инновационного развития, цифровая платформа «Единое окно инноваций», партнерство с технопарками и инновационными кластерами (Сколково, Иннополис и др.). Описаны механизмы поддержки проектов на всех этапах — от идеи (кванториумы, бизнес-инкубаторы, конкурсы «Новое звено» и «Идея» ОАО «РЖД») до тиражирования (Программа поддержки инноваций ОАО «РЖД»).

Особое внимание уделено управлению интеллектуальной собственностью: портфель ОАО «РЖД» насчитывает свыше 4700 объектов (программное обеспечение, изобретения, полезные модели, товарные знаки). Рассмотрены меры по защите интеллектуальной собственности, судебно-претензионная работа и стратегия коммерциализации.

Авторы приходят к выводу, что системная инновационная политика, интеграция внутренних и внешних ресурсов, фокус на технологическом суверенитете и управлении интеллектуальным капиталом обеспечивают ОАО «РЖД» лидерство в транспортной отрасли.

КЛЮЧЕВЫЕ СЛОВА: инновации; ОАО «РЖД»; управление инновациями; инновационная экосистема; форсайт; бенчмаркинг; открытые инновации; интеллектуальная собственность; технологическое развитие; региональные центры инновационного развития; цифровая платформа; технологическая суверенитет

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## INTRODUCTION

Rail transport plays a vital role in the development of national transportation systems and economies. Railways create new transport corridors, improve regional connectivity, develop domestic tourism and help shape a comfortable and safe environment for millions of people — both passengers and shippers. The appearance of new technologies opens up new horizons and opportunities for innovative development in rail transport. The implementation of innovations allows railway companies to respond quickly to changes in consumer preferences and the market environment, helping increase the competitiveness of rail transport compared to road and air transport.

The innovative development of Russian Railways (JSC RZD) is inextricably linked with the prospects, goals, and objectives of the country in general, which are defined in the Concept of Technological Development of the Russian Federation for the period up to 2030, the national goals for the Russian Federation up to 2030 and up to 2035, and Federal Law No. 523-FZ “On the Technological Policy of the Russian Federation” dated 28 December 2024.

## THE STRATEGIC VECTOR OF INNOVATIVE DEVELOPMENT

Russian Railways is one of the largest and most innovative railway companies in the world today. The company embarked on a strategic course towards innovative development in 2007 following a rebranding and a review of the company’s business development strategy. The Center for Innovative Development (hereinafter referred to as the Center) was established in 2009 to organize the innovative activities of this vertically integrated and systemically important company in Russia [1][1]. The Center became an integrator of new competencies and the basis for the development of an

[1] List of Systemically Important Organizations of the Russian Economy: Approved by Minutes No. 3 of the Meeting of the Government Commission to Increase the Sustainability of the Development of the Russian Economy dated 20 March 2020. Available at: https://www.consultant.ru/document/cons_doc_LAW_349267/40833be0fb65511bddc7cff58090c734a22b7ab3/.

innovative ecosystem and the dissemination of an innovation culture throughout the country's network.

This came after the appearance of various internal and external factors that led to an increased need for the following processes:

- the development of interaction with manufacturing companies and small tech entrepreneurs at the regional level;
- the development of systematic work with the executive authorities, research organizations, state corporations, and other structures on issues related to innovative activities;
- a transition from targeted work with promising projects and initiatives at the local level to the creation of a centralized system uniting JSC Russian Railways, its branches and other structural divisions and regulating work with innovations at all stages of their implementation.

The Government of the Russian Federation set the task of implementing innovative development programmes in 2010[2, 3]. Just one year later, the JSC Russian Railways Board of Directors approved its Innovative Development Programme for the period up to 2015 (IDP 2015), marking the launch of systematic work in priority areas of the company's innovative development. The basic principles of technological development were established, defining the timeline for the implementation of resource-saving technologies, the creation of modern transport and logistics systems, and the complete overhaul of rolling stock and infrastructure in line with the best international practices.

The Center has come a long way since its establishment 16 years ago, as have the innovative activities at JSC Russian Railways:

- Planning horizons have been expanded; organizational changes have been introduced to support innovations and new strategic areas for development have been established: import substitution, the involvement of external organizations (universities, tech companies, development institutions) in solving the company's problems, protecting and developing its own intellectual capital.
- A comprehensive system of support for innovative projects and a functional vertical structure have been created that oversees the central and regional levels of innovation management and extends to subsidiaries of JSC Russian Railways.

However, the company has faced new challenges since 2020: the COVID-19 pandemic; sanctions; the withdrawal of Western companies from the Russian market; problems with staff retention and much more. The response to these challenges was a rethinking of the innovative development priorities, with a focus on ensuring technological sovereignty and improving the safety of rail transport. The company focused on ensuring transport accessibility across the country, improving services, enhancing comfort and speed for passengers and freight, improving the quality of transportation, and developing new types of services based on the latest technologies. Russian Railways is focused more than ever on improving energy efficiency and environmental friendliness, automation, robotics, and AI implementation.

Today, Russian Railways is working with the business community to develop hi-tech areas relevant to the government and is also implementing national projects that create new opportunities for accelerating the technological development of rail transport in Russia.

## THE ARCHITECTURE OF THE INNOVATION ECOSYSTEM

The Russian Railways Holding's innovation ecosystem combines sources of "in-house" innovations (for example, the scientific-industrial complex) and tools for attracting and adapting external innovative solutions and technologies.

1. Science institutes — RZD subsidiaries (Railway Research Institute, RIIZT; Scientific Research Institute of Railway Transport; All-Russian Research and Design Technological Institute of Rolling Stock, VNIKTI; Institute of Transport Economics and Development, IERT; etc.), design bureaus and research laboratories attached to the largest research and technological centres in Russia (for example, the Innovation Center for Railway Transport, a resident of the Skolkovo Innovation Center), specialized JSC RZD research laboratories in the Lomonosov cluster (*Fig. 1*), and others ensure the continuity and development of engineering knowledge and expertise in fundamental areas of railway transport, and are directly involved in applied R&D for JSC RZD and the rail industry.

2. Understanding that breakthrough technologies often emerge outside the industry, Russian Railways has built an extensive system of interaction with the external innovation environment. The partner network includes hundreds of technology parks, industrial clusters, and industrial competence centres (such as the Moscow Innovation Cluster Fund, MIC Fund;

[2] Instruction No. Pr-22 of the President of the Russian Federation on the Results of the Work of the Presidential Commission on the Modernization and Technological Development of the Russian Economy dated 4 January 2010.

[3] Minutes No. 4 of the Meeting of the Government Commission on High Technologies and Innovations dated 3 August 2010 (Para. 4).

**Fig. 1.** Quantum Communications Center in the Lomonosov Cluster. Photo provided by the press service of Russian Railways

the Skolkovo Foundation; Joint Stock Company Technopark of Novosibirsk Academgorodok, Academpark Innopolis Special Economic Zone in Tatarstan, Open Joint-Stock Company Lenpoligrafmash in St. Petersburg, and many others). The main goal of this partnership is to identify, adapt, or jointly develop promising domestic technologies to meet the requirements of rail transport in such areas as unmanned vehicles, new materials, intelligent surveillance systems, digital platforms, and others.

Regional Innovation Development Centers (RIDCs) have been established on all the country's railways, ensuring productive interaction between JSC RZD divisions and innovative solutions developers (small tech companies, industrial enterprises, scientific and production organizations).

The Center for Innovative Development coordinates the activities of all elements of the Russian Railways Holding's innovation management system:

- *strategic planning:* the Center defines the priority areas of technological development, which in turn form the basis of "road maps" for all participants in the innovation ecosystem;
- *methodological support:* within its scope of responsibility, the Center provides the methodological base for the company's structural divisions (directorates, branches), which makes it possible to create standardized and effective project development processes "on the ground," bringing innovations as close as possible to the end customer — the company's divisions;
- *External project portfolio management:* end-to-end management of open innovation projects — from collecting information on the needs of the company's units, searching for and evaluating relevant innovative solutions, to selecting tools for adapting and refining them and organizing pilot testing, implementation, and subsequent replication across the network;
- *Systemic work with the external environment:* the Center serves as a "one-stop shop" for thousands of external tech suppliers, structuring their requests and proposals and directing them to the appropriate units;
- *Intellectual property management:* legal protection and commercialization of JSC RZD's intellectual activities results.

## FORECASTING, PLANNING, AND DISTRIBUTION OF TASKS

In the context of the rapidly changing macroeconomic situation, the company has established a process for developing strategic priorities for the short- (three to five years) and long-term (20–30 years) planning horizons to promptly identify new areas for the development of rail transport and introduce innovations into the activities of JSC RZD.

The main tools used in this process are foresight and technological comparisons, integrated into the innovation management system of the Russian Railways Holding. These tools allow us to analyse promising trends in the development of the transport industry, as well as in the Russian and global socio-economic systems, and identify best practices and solutions based on the experience of the most tech-savvy companies.

Foresight and technological comparison (benchmarking) are quantitative, qualitative, and expert forecasting and analysis methods that are used to assess the current company's innovative development level and formulate a development strategy that identifies promising vectors for achieving set goals. The process involves analysing the strategic documents of countries and companies, reports of international organizations, and patent databases.

Foresight is the main tool of technological forecasting, based on the analysis of extensive flows from various sources. Focus groups are a big part of the foresight process, which involves brainstorming sessions and the tracking of futurological forecasts. The expert community's involvement in this activity is in the form of hundreds of multidisciplinary experts in the most important areas of scientific, technological, and engineering development. Dialogue with them allows Russian Railways to assess the speed of breakthrough innovations, determine the impact of technological changes on rail transport, and, through joint efforts, model the most effective development scenarios.

The first Russian Railways foresight study was completed in 2021. It focused on technological development and had a forecast horizon that extends to 2050. The global trends identified and the factors that characterize them allowed the Center to forecast potential scenarios for long-term technological development and

**Fig. 2.** Lastochka Driverless Electric Train on the Moscow Central Circle

**Fig. 3.** Operator monitoring the movement of the Lastochka Driverless Train on the Moscow Central Circle

**Fig 4.** Chelyabinsk-Glavny Station, where construction of a multifunctional digital railway station (Smart Station) is being completed

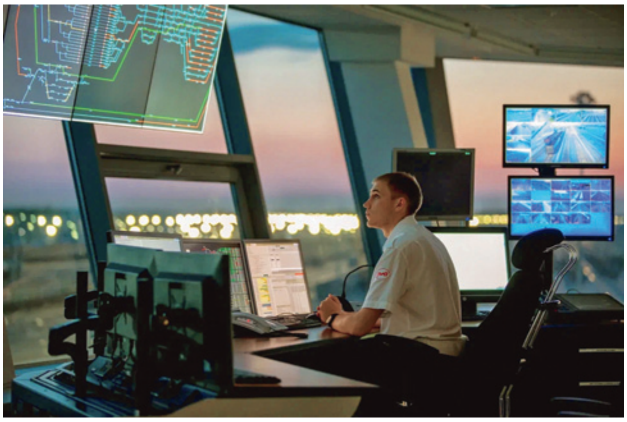

**Fig. 5.** Duty Officer at Chelyabinsk-Glavny Station

Photos provided by the press service of Russian Railways

establish new requirements for the future transport infrastructure, rolling stock, and transport process[4] [4].

In addition, every year, JSC Russian Railways engages independent experts to help assess its technological development measures compare to other railway companies around the world. For example, in 2024, the company carried out a comprehensive comparison of the business models of 60 companies across 70 performance indicators and 34 technology areas. Key areas that were analysed include transport logistics, transportation management, digitalization, hi-tech solutions implementation, the development of innovative rolling stock and infrastructure, energy efficiency improvement, environmental friendliness, and the transportation process safety.

Foresight and benchmarking allow companies to move from technological forecasts to planning activities and setting specific objectives based on reserves for growth and the achievement long-term goals. In the period from 2018 to 2025 alone, JSC Russian Railways, JSC RZD updated the Holding's key strategic documents and launched several cross-functional innovative products, including:

- The launch of an experimental electric train service on the Moscow Central Circle (MCC), where the driver simply monitors the equipment, while an intelligent system steers the train autonomously (*Fig. 2*, *Fig. 3*).
- The construction of a multifunctional digital railway station (smart station) at Chelyabinsk-Glavny Station, which is almost complete. Advanced robotics and digital solutions and systems are being implemented to ensure a full cycle of automation and robotization of its technological processes (*Fig. 4*, *Fig. 5*).
- The launch of construction of a high-speed railway line on the Moscow – St. Petersburg section. Innovative track and catenary system designs are cur-

[4] RZD 2050: Looking Beyond the Horizon. Ed. by V. Saraev. Moscow: Innopraktika. Available at: https://company.rzd.ru/ru/9990/page/103290?id=19093#main-header.

rently being created for this. and a train that will operate at speeds of up to 360 km/h on the line is being developed domestically.

## "OPEN THE DOORS": IMPLEMENTING THE "OPEN INNOVATION" FORMAT

Over the past two decades, the speed at which technology is progressing has become a critical factor in the development of major companies. Many corporations (Russian Railways included) have leveraged their own sources of innovation, with the entire cycle — from research and development to implementation — being contained within the company itself. In the context of the digital revolution, those who deliberately started to incorporate "external" ideas and technologies in a line with their own in-house developments gained a competitive advantage.

Working with innovations created by third parties has enabled Russian Railways to transition from isolated experiments to the creation of a sustainable system of continuous research, testing, adaptation, implementation, and replication of new technical and technological solutions. This has led not only to the implementation and large-scale rollout of specific technological solutions across the company's infrastructure, but also to the development of a culture of innovation, which is reflected in the openness of its employees to anything new and a willingness to seek new solutions to current challenges, including challenges outside of the company.

The regional innovation development centres established from Kaliningrad to Khabarovsk have played a crucial role in this.

Regional centres articulate the Holding's needs and harness the scientific and industrial potential of the constituent entities of the Russian Federation to address the most pressing challenges facing the company.

The centres serve as attraction points for innovative activity in the regions, localizing the company's objectives. For example, on 21 April every year, the regional centres celebrate Russian Railways Innovation Day, timed to coincide with World Creativity and Innovation Day. Every year, up to 10,000 Russian Railways employees, tech entrepreneurs, government representatives, development institutions, research organizations and universities, and innovative manufacturing enterprises take part in Russian Railways Innovation Day events across the country.

The Oktyabrsky Center for Innovative Development opened by JSC RZD CEO and Chairman of the Board Oleg Belozerov and Governor of St. Petersburg Alexander Beglov in June 2019 was the first of its kind.

Another key element of the open innovation process was the creation of a unified digital platform — the "JSC RZD Single Window of Innovation" — to accept technology requests from the Holding's customer divisions and innovation initiatives from external parties.

This way, not all technologies are developed exclusively within the company, allowing it to borrow best practices from other industries and integrate them into its production processes, including through long-term partnerships with the scientific and technological community. Developers from outside the company propose solutions, while experts in the relevant areas at the company evaluate their potential application, adaptation, and implementation.

The fact that all participants in the project selection process have access to a single digital platform, coupled with the fact that the regional centres are distributed more or less evenly across the country's railway network, means that submissions can be reviewed at the centre for innovative development that is closest to the applicant and then tested on the railway whose needs and specific features they address (climate conditions, logistics infrastructure, etc.). This type of information exchange makes it possible to quickly replicate promising solutions that have undergone successful testing in one region on other railways.

More than 10,000 external innovative proposals have been submitted and reviewed in the seven years since the platform's launch.

## COMPREHENSIVE SOLUTIONS FROM IDEA TO ROLLOUT

JSC RZD Russian Railways is developing a corporate ecosystem for innovation activities, integrating various tools to support promising projects to scale up the implementation of innovative solutions, accelerate their adaptation, and attract external funding to refine projects in the company's interests (*Fig. 6*).

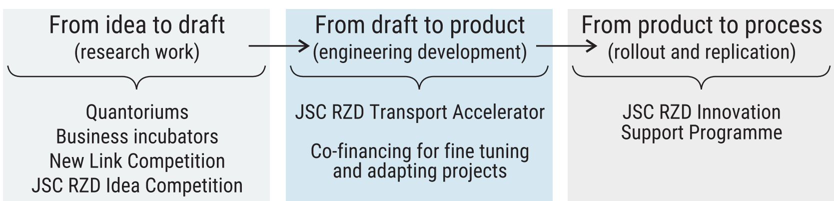


**Fig. 6.** Support Mechanisms for Innovative Projects

JSC RZD has a comprehensive system of support for innovative projects at all stages of their life cycle — from a promising idea to the project's rollout at railway sites.

One of the company's strategic priorities is the development of human capital. The development of innovative thinking in future specialists starts at school — at the Quantorium children's tech parks and the business incubators at the country's leading transport universities. Here, schoolchildren and students master the basics of technical creativity and project work and learn the fundamentals of business.

One example is the joint student business incubator set up by the Oktyabrskaya Railway and Emperor Alexander I St. Petersburg State Transport University, where heads of production departments provide support for projects developed by future specialists and encourage student entrepreneurship through consulting and project assessment.

In addition, large corporate competitions are held every year within the company, serving as a "social lift" and way of "monitoring" promising ideas put forward by employees. The "New Link" youth project competition and the JSC RZD "Idea" Innovation Proposal Competition attract an impressive number of participants every year — more than 5000 people submitting approximately 2000 projects and initiatives for expert review. The most promising of these go through acceleration programmes before in-depth development and implementation.

Key in the development of the innovation ecosystem is the practice of attracting external financing. JSC RZD actively works with the constituent entities of the Russian Federation and foundations that support scientific activities. To systematize this work, the company has compiled and constantly updates a list of more than 70 federal and regional support programmes.

The Russian Railways Innovation Support Programme serves as the corporate financial support instrument, and it has been running since 2022. Approximately 200 projects run by 28 company divisions have been financed since its launch through direct financing, which demonstrates the demand for this mechanism and its role in bringing promising developments to the implementation stage.

## PROTECTING AND MANAGING RZD'S INTELLECTUAL CAPITAL

In today's economy, the value of a company is measured not only by its tangible assets, but also by its intellectual capital.

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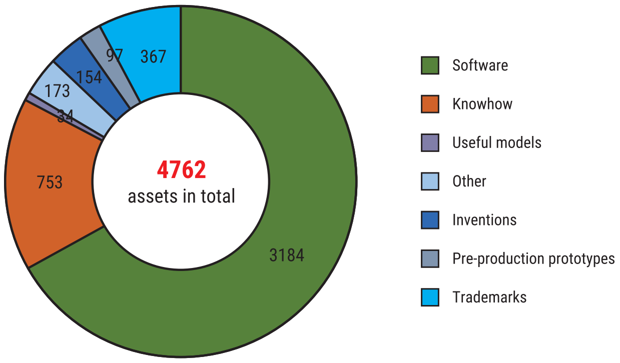


**Fig. 7.** JSC RZD Intellectual Property Portfolio as of 1H 2025

For such a technically complex and massive corporation as Russian Railways, intellectual property (IP) is a significant strategic resource. Having one of the largest IP portfolios among companies with state participation (more than 4700 assets, per 1H 2025 results *Fig. 7*), JSC RZD has built a comprehensive and proactive system for its protection and management.

The Russian Railways IP portfolio is a dynamically developing structure that includes all types of results of intellectual activity (RIA) that are granted legal protection in accordance with the law. Since the beginning of 2025 alone, Russian Railways has been granted intellectual property rights (patents and certificates) to over 300 assets. The portfolio structure (see *Fig. 2*) clearly demonstrates the company's digital transformation: nearly 70% of the IP portfolio is made up of computer programs. This is the core of the digital infrastructure that powers the entire enterprise — from transportation management systems to customer services.

Approximately 20% of the JSC RZD IP portfolio consists of registered inventions and useful models that protect breakthrough technical solutions in the field of traction, infrastructure, and logistics. A regulatory framework is the basis for managing these assets. Several internal documents were revised and updated in 2024–2025 that regulate the company's activities at various stages of the IP lifecycle — from identifying promising developments to their commercialization. Among these is the company's key document in this area — the IP Management Strategy for the Period up to 2030 (hereinafter referred to as the Strategy) — is undergoing approval. Among the priorities outlined in the strategy are ensuring the company's technological sovereignty and leadership. Thus, working with IP not only protects significant investments in R&D from potential plagiarism, but it also allows the company to benefit from the use of new, superior developments.

Another area of the Russian Railways' work is the protection of its trademarks. The company has established a practice of registering all names used. However, legal protection alone is not always sufficient to combat IP theft. Since 2024, the Center for Innovative Development has been working alongside the company's legal department to conduct systematic litigation and claims work. Practice shows that the claims stage is frequently ignored by the guilty parties. The response to this is to initiate legal proceedings. In 2024–2025 alone, approximately 300 violations were suppressed, a significant portion of which concerned the sale of counterfeit products online (goods bearing the Russian Railways logo, for example).

Not only does this work bring benefits in terms of monetary compensation, but it also serves a preventative purpose. The information that is made public about Russian Railways actively initiating claims for IP violation and the amounts the company has received in compensation for such violations is creating a new reality in which offenders are forced to take the risks into account. In addition to protecting the company's rights, measures are also being taken to commercialize its intellectual property.

Every year, JSC RZD enters into licensing agreements for the right to use its IP, demonstrating that it is in demand not only within the company, but also in related markets. The Strategy assumes that income from the use of the IP portfolio will continue to grow.

Thus, JSC RZD's IP activities are developing from solving tactical problems of registering and protecting IP to building a strategic system that is able to anticipate potential challenges. The company's large and diversified portfolio, supported by the digitalization of patent documentation and an active legal position, has become a key asset ensuring the Holding's technological leadership and sustainability. Intellectual property is no longer simply a legal formality; it is a fully fledged tool for managing innovation and strengthening national technological sovereignty in a critically important area — rail transport.

## CONCLUSION

The railway is a complex system of transport, energy, services, environment, and people that transforms rails, stations, and rolling stock into a single, living organism. It is a sustainable ecosystem that ensures the seamless fusion of customer needs, innovative technologies, and engineering expertise.

JSC RZD's continuous innovation system is a key factor in the company's accelerated growth: cutting-edge developments allow Russian Railways to continually improve service quality, safety, mobility, and comfort. Its flexible and systematic approach to planning innovation activities and implementing innovative projects, the innovation management ecosystem it has established, and its partnerships with organizations in the external innovation environment ensure that Russian Railways is one of the most innovative and hi-tech transport companies in the world.

## Bionotes

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# Development of infrastructure for conventional and high-speed railways: comparative analysis[1]

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ABSTRACT High-speed rail service turns 60 in 2024, and 2025 is the bicentennial of rail transport. In this regard, the paper provides a comparative analysis of the development trends of conventional and high-speed rail infrastructure. The main objective of the work is to study the dynamics of the development of the two types of railway infrastructure, their impact on society and the global economy. The study is based on statistical analysis of data on the length of railways and discusses examples of various countries that played a key role in the development of both conventional and high-speed rail systems.

KEYWORDS: global railway network; railway infrastructure; high-speed rail infrastructure; HSR; socio-economic effects

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*Научная статья*

## Развитие инфраструктуры традиционных и высокоскоростных железных дорог: сравнительный анализ[1]

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АННОТАЦИЯ Высокоскоростному железнодорожному сообщению в 2024 г. исполнилось 60 лет, а 2025 — год двухсотлетия железнодорожного транспорта. В связи с этим выполнен сравнительный анализ тенденций развития традиционной и высокоскоростной железнодорожной инфраструктуры. Основной целью работы является изучение динамики развития двух типов железнодорожной инфраструктуры, их влияния на общество и мировую экономику. Исследование основано на статистическом анализе данных о протяженности железных дорог. Рассмотрены примеры различных стран, которые сыграли ключевую роль в развитии как традиционных, так и высокоскоростных железнодорожных систем.

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КЛЮЧЕВЫЕ СЛОВА: мировая сеть железных дорог; инфраструктура железных дорог; высокоскоростная железнодорожная инфраструктура; ВСМ; социально-экономические эффекты

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## INTRODUCTION

The year 2025 marks the bicentennial of rail transport. The year 2024 was the 60th anniversary of high-speed rail (HSR). In view of the proximity of the two important anniversaries, it would be relevant to carry out a comparative analysis of the development of both conventional and high-speed rail infrastructures in the world.

For the purposes of the analysis, it would be appropriate to consider 60-year long periods. Given that fully operational steam-powered railways emerged in 1830 and this happened in different countries and even parts of the world [1], it would be appropriate to consider a period between 1830 and 1890 as the relevant period of the development of conventional railways. This will ensure the comparability of the basic values of the global length of conventional railways (about 400 km in 1830) and high-speed rail lines (515 km in 1964).

## COMPARING THE GROWTH IN LENGTHS OF CONVENTIONAL AND HIGH-SPEED RAIL NETWORKS

Both conventional and high-speed rail networks demonstrated impressive growth over the respective 60-year periods (*Fig. 1*, *2*). Changes in the length of the global network of conventional railways are best described by a power-law trend (the coefficient of determination $R^2$ is close to 1). Changes in the length of the global HSR network are more precisely described by an exponential trend (the coefficient of determination is also close to 1). This suggests that the development of the infrastructure for conventional and high-speed rail lines follow different patterns. The difference has an economic interpretation.

The conventional railway infrastructure, the construction of which was commercially efficient [2, 3], began to be built quite quickly in many countries, not only in highly developed ones [4]. Being much more advanced technologically and expensive than construction of conventional railways, HSR construction is usually not commercially efficient and generates effects of social and economic nature [5–11]. Hence, high-speed rail construction requires significant public funding, which is only possible in highly developed or rather large medium-developed economies.

In the 19th and early 20th centuries, the construction of conventional railways served as a tool to accelerate the development of countries, including as part of economic catch-up strategies, even from the very low start. In the 20th and early 21st centuries, the fact that a country builds high-speed rail indicates that it has achieved quite a high level of social and economic development, where, on the one hand, it can afford having high-speed rail service, and on the other hand, it has to do so for the sake of further development of its society and economy, as many other development tools have been already utilized and largely exhausted.

Japan is a vivid example of this. It started building railways as late as 1868 [4], when dozens of other

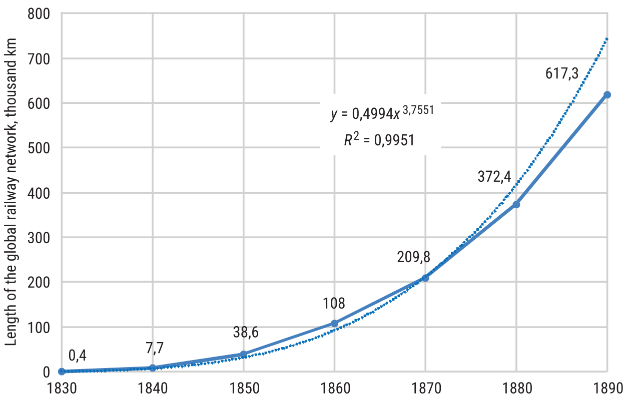


**Fig. 1.** Changes in the length of the global conventional railway network, 1830–1890

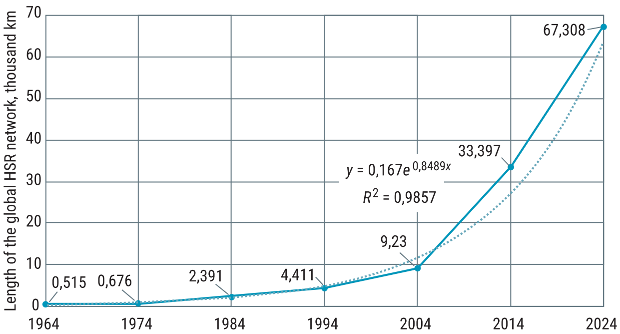


**Fig. 2.** Changes in the length of the global HSR network, 1964–2024 (data for 2024 are estimated values)

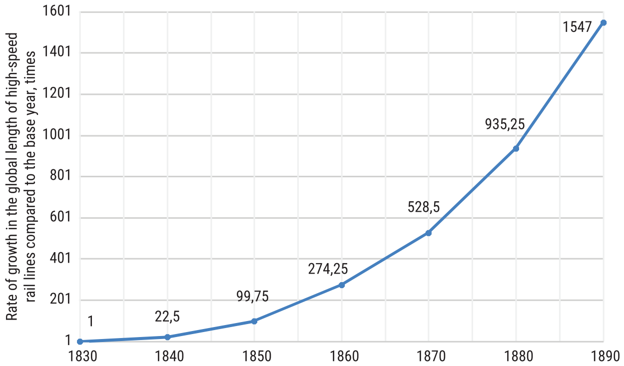


**Fig. 3.** Rates of growth in the length of the global conventional railway network, 1830–1890

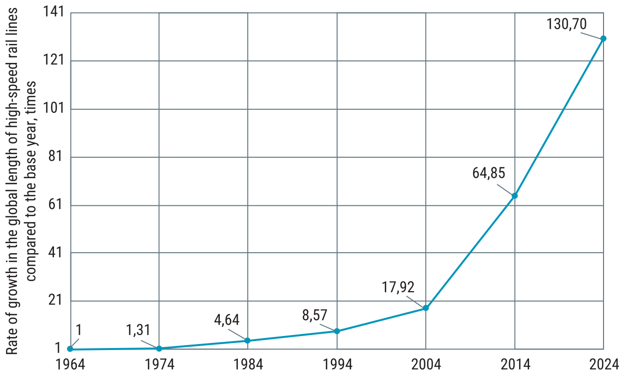


**Fig. 4.** Rates of growth in the length of the global high-speed rail network, 1964–2024

countries already had railways[2] and the total length of the global railway network was about 200 thousand km [13]. High rates of railway construction in Japan in the late 19th and early 20th centuries were one of the major tools of the catch-up development strategy implemented at the time. In 1870, Japan's GDP per capita was 84% of the world average, and by 1913 it was as high as 91%. Nevertheless, Japan still substantially lagged behind economic development leaders. The world's first high-speed railway line was launched in Japan less than one hundred years after the start of railway construction in the country, in 1964. It was no longer a catch-up development tool, but one of the outcomes of the country's successful post-war progress known as the "Japanese economic miracle" [15], which ultimately made Japan one of the global economic leaders.

When characterizing differences in the development of the global network of conventional and high-speed railways, it is very important to compare growth rates for each of the networks (*Fig. 3, 4*).

While the absolute growth values for the global network of conventional railways increased from one decade to another (see *Fig. 1*), the growth rates of their network gradually decreased (see *Fig. 3*).

The dynamics of the HSR network growth rates changed nonuniformly (see *Fig. 4*). Worth mentioning are two periods when its growth accelerated: first, between 1974 and 1984, when the high-speed rail network began to develop in Europe, and second, between 2004 and 2014, when the acceleration was driven by high growth rates in HSR construction in China which currently has more than two thirds of the global high-speed rail network.

## COMPARING THE CONCENTRATION OF CONVENTIONAL AND HIGH-SPEED RAIL NETWORKS

An analysis of the concentration of the global HSR network in comparison with the conventional railway network is worth a separate note.

By the end of the 60-year period in question (1890), the majority (90%) of conventional railways were concentrated in the United States and Europe. At the same time, a notable portion (10%) was accounted for by other parts of the world: Asia, Africa, and Australia (*Fig. 5*).

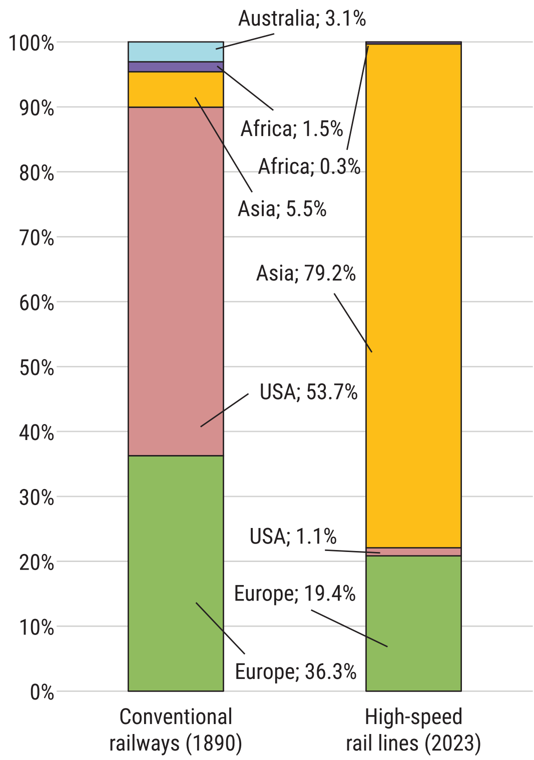


**Fig. 5.** Concentration of conventional railways (1890) and HSR (2023) by part of the world by the end of the respective 60-year period of development

[2] In particular, as early as 1867, the length of Russian railways exceeded 5,000 km and was growing rapidly [12].

The concentration of the HSR network (as of 2023) was even higher: it was nearly entirely (98.6%) concentrated in Eurasia, with Asia accounting for four times more than Europe.

Worth noting is that although they first appeared in Europe, by the end of the 19th century, conventional railways were the longest in the United States. On the other hand, high-speed railways first appeared in Asia and are also developing most dynamically in this part of the world. However, in both cases, the growth was related with passing the baton from the country that pioneered in the construction of railways (Great Britain for conventional railways and Japan for HSR) to the country with the longest network length (the United States and China, respectively). The diffusion of innovation in the railway sector (and in transport in general) significantly increases the efficiency of both industry and macroeconomic development [16, 17].

Representative is the data on the top ten countries in terms of the length of infrastructures for conventional railways (in 1890) and HSR (in 2023) (*Tables 1, 2*). For conventional railway infrastructure, the leading country accounted for 43.5%, the top five countries accounted for 66.9%, and the top ten countries accounted for 83.0% of the total global network length (see *Table 1*), while for high-speed rail, the figures are 70.2%, 88%, and 95.8%, respectively. In other words, the share of the HSR leader (China) exceeds that of the top five countries in terms of length of conventional railway infrastructure, and the share of the top five countries for HSR exceeds that of the top ten countries for conventional railway infrastructure.

*Table 1*

**Top 10 countries in terms of length of conventional railways in 1890**

| List position | Country | Length*, thousand km | Percentage, % | Percentage (cumulative), % |
|---|---|---|---|---|
| 1 | United States | 268.409 | 43.5 | 43.5 |
| 2 | Germany | 42.869 | 6.9 | 50.4 |
| 3 | France | 36.895 | 6.0 | 56.4 |
| 4 | Russia and Finland | 32.39 | 5.2 | 61.7 |
| 5 | Great Britain and Ireland | 32.297 | 5.2 | 66.9 |
| 6 | Austria-Hungary | 27.113 | 4.4 | 71.3 |
| 7 | British East Indies | 27 | 4.4 | 75.6 |
| 8 | Canada | 22.533 | 3.7 | 79.3 |
| 9 | Italy | 12.907 | 2.1 | 81.4 |
| 10 | Spain | 9.878 | 1.6 | 83.0 |
| | World Total | 617.285 | | |

* Compiled by the authors on the basis of [13].

*Table 2*

**Top 10 countries in terms of length of high-speed railways in 2023**

| List position | Country | Length*, thousand km | Percentage, % | Percentage (cumulative), % |
|---|---|---|---|---|
| 1 | China | 45.390 | 70.2 | 70.2 |
| 2 | Spain | 3.993 | 6.2 | 76.3 |
| 3 | Japan | 3.147 | 4.9 | 81.2 |
| 4 | France | 2.760 | 4.3 | 85.5 |
| 5 | Germany | 1.631 | 2.5 | 88.0 |
| 6 | Turkey | 1.232 | 1.9 | 89.9 |
| 7 | Finland | 1.120 | 1.7 | 91.6 |
| 8 | Italy | 0.921 | 1.4 | 93.0 |
| 9 | Sweden | 0.895 | 1.4 | 94.4 |
| 10 | South Korea | 0.874 | 1.4 | 95.8 |
| | World Total | 64.7 | | |

* Compiled by the authors on the basis of [18].

Thus, the above analysis shows that concentration is significantly higher for HSR than for conventional railways (after an equivalently long period of development), both by country and by part of the world.

## MACROECONOMIC PERSPECTIVE

The development of conventional railway infrastructure promoted economic growth. Paper [4] found a positive correlation between the level of economic development of countries and the level of development of conventional railway infrastructure.

In the modern context, there is a positive correlation between the level of economic development and the level of development of high-speed rail infrastructure: there is a direct correlation between the countries' share of global Gross Domestic Product at Purchasing Power Parity (GDP PPP) and their share of the global HSR network (*Fig. 6*). The coefficient of determination $R^2 = 0.5886$ suggests a rather high quality of the regression line and shows, based on [19, 20], that 59% of the cumulative variation in the countries' share of global GDP is described by their share of the global HSR network. The corresponding linear correlation coefficient (0.7672) enables us to conclude, on the basis of the Chaddock scale, that there is not just a direct, but a *strong* direct correlation between a country's share of the global GDP and its share of the global HSR network.

A comparison of changes in economic growth and the length of HSR lines in countries with the largest high-speed rail networks (China, Spain, and Japan) shows that the fact that a country starts HSR construc-

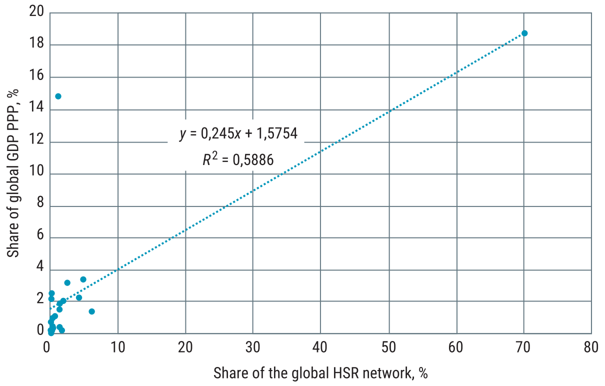


**Fig. 6.** Dependence of countries' share of the global GDP PPP on their share of the global HSR network

tion is indicative of its significant progress in economic growth and subsequent development of high-speed rail service adds impetus to the economic growth.

Thus, economic growth and development of high-speed rail infrastructure are mutually supportive processes with a positive inverse correlation between them.

In this context, the launch of the project for building Russia's first HSR line between Moscow and St. Petersburg is a landmark event [8, 21, 22]. First, it demonstrates that the Russian economy has reached an appropriate level of development and second, it paves the way for the acceleration of economic growth in Russia.

While the total length of the global HSR network is more than nine times shorter than that of the global conventional railway network built during the first 60 years of its development, given the significantly higher cost of HSR construction, the estimated investment in the high-speed rail infrastructure can be approximately as high as five times the investment in the conventional railway infrastructure over the equivalent period. This is a good illustration of the current "renaissance" of rail transport as one of the innovative leaders among sectors of the world economy [23].

At the same time, it is the high cost of building HSR lines that provides an economic basis for the concentration of the network of HSR lines identified in countries with rather large economies.

## CONCLUSION

Our analysis enables us to draw meaningful conclusions on the development of high-speed rail infrastructure in comparison with conventional railways.

The nature of railway infrastructure development is determined by economic factors, such as its cost and specific features of the effects it generates [24]. With relatively low costs and significant commercial effects (conventional railways), the construction and expansion of railway infrastructure across countries and continents is much more dynamic than when costs are high and effects are mainly social and macroeconomic (HSR). This conclusion is important in view of the proposed construction of maglev and vacuum levitation lines in the future [5, 25].

Compared to conventional railways, HSR is not only a more expensive mode of transport, but it is also more specialized. While in the 19th century, railway construction had virtually no alternatives as a general-purpose tool to promote modernization of economies, in the 21st century, HSR should fit into a much more developed transport system featuring versatile capabilities and compete with other modern modes of transport, first of all, air transport. Therefore, for the HSR network to develop, it is quite essential to competently implement the social, economic and environmental benefits it offers and position them in society.

Finally, an important methodological conclusion as to the long-term analysis of transport infrastructure development is that a comparative analysis of the development of various types of transport infrastructure in different periods of history can be meaningful, provided the relevant time periods are comparable.

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# “T” — loading gauge wagons: Prospects of creation and problems of introduction

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ABSTRACT The paper discusses the advantages of “T” — loading gauge freight wagons. It shows that their use will enable countries with the 1,520 mm track gauge to increase the carrying capacity of their railways by increasing the weight of trains, reduce the required fleet size on account of higher capacity of wagons and cut traction costs, while also reducing shipping costs for consignors. The paper reviews the challenges related to the introduction of “T” — loading gauge wagons due to the reduced clearances on the railway network and insufficient bridge load capacity.

KEYWORDS: rolling stock; freight wagons; “T” — loading gauge wagons; load capacity; capacity; linear load

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*Научная статья*

## Перспективы создания и проблемы внедрения вагонов габарита Т

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АННОТАЦИЯ Рассмотрены преимущества применения грузовых вагонов габарита Т. Показано, что их применение позволит странам колеи 1520 мм повысить провозную способность железных дорог увеличением веса поездов, уменьшить потребный парк вагонов за счет их большей вместимости, сократить расходы на тягу поездов, а грузоотправителям — снизить расходы на отправку грузов. Анализируются проблемы внедрения вагонов габарита Т, связанные с наличием негабаритных мест на сети и недостаточной грузоподъемностью мостов.

КЛЮЧЕВЫЕ СЛОВА: подвижной состав; вагоны грузовые; габарит Т; грузоподъемность; вместимость; погонная нагрузка

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## INTRODUCTION

The challenge of increasing the carrying capacity and throughput capacity of 1.520 mm gauge railways is becoming increasingly relevant as freight turnover is growing, even while rail loadings are decreasing. In 2018–2024, the main railway infrastructure in the Russian Federation underwent comprehensive modernization and expansion in accordance with the Decree of the President of Russia dated May 07, 2018. In 2024, more than RUB 1 trillion was allocated to infrastructure development and renovation projects alone [1].

The carrying capacity of railways at the approaches to the Azov and Black Sea Basin and in the Eastern operating domain increased 1.5 times compared to 2018. The construction projects completed in 2024 resulted in an increased carrying capacity of the Eastern operating domain which reached 180 million tonnes. However, even at this level, the carrying capacity is still not sufficient. The goal is to increase the carrying capacity to 210 million tonnes in the Eastern operating domain, to 152 million tonnes for rail lines to the ports in the Azov and Black Sea Basin, and to 220 million tonnes for the North-West Region. In addition, because of a shortage of public tracks, there is a problem of parking excessive empty freight wagons. How can these problems be solved in the future when the investment programme of Russian Railways JSC has been reduced by 40%?

The development of heavy-haul traffic is considered one of the solutions to the problems [2, 3]. There are three areas in the development of heavy-haul traffic:

- Operating longer trains with an increased weight;
- Operating trains of a standard length but a higher weight made up of wagons with a higher load capacity by increasing the allowable axle load to 27–30 tf;
- Operating trains of a standard length but a higher weight and increased linear load while maintaining the current permissible axle load of 25 tf.

## OPERATING HEAVIER TRAINS: BALANCING HIGHER CARRYING CAPACITY AND RISKS FOR INFRASTRUCTURE

Making up longer trains of existing wagons will allow for some increase in carrying capacity. However, due to the need to occasionally break them down into sections to fit the length of receiving and departure tracks for the purposes of maintenance, handling of passenger trains, and replacement of locomotives and locomotive crews, this will reduce the throughput capacity of railways and can only be used on certain directions.

The most efficient way would be to operate heavier trains made up of wagons with an increased load capacity by increasing the axle load to 27–30 tf [4, 5]. However, according to some experts, this will result in lower strength and stability of the subgrade formation and in damaging artificial structures [6–8].

These concerns are shared by the management of Russian Railways and administrations of many other railways in the 1520 Space.

Therefore, the implementation of this solution has been postponed for an indefinite period, although it was included in the original Strategy for the Development of Railway Transport in the Russian Federation until 2030, and tests conducted on the Smychka–Kachkanar section showed that wagons with an axle load of 27 tf on improved bogies could be operated without a noticeable deterioration of the track condition [9].

Operating heavier standard-length trains with an increased linear load allows achieving higher carrying capacity without reducing the throughput capacity. After all, all the railways in the 1520 Space are designed for the permissible linear load of 10.5 tf/m, except for some older bridges. Therefore, in the modern context, this solution is seen as the primary one for increasing the carrying capacity of railways [10].

In order to increase the carrying capacity of railways, it is important to increase the net linear load, i.e. the weight of freight per metre of the wagon length, rather than the gross linear load. This can be achieved by increasing the wagon static load, reducing the wagon tare weight, and shortening the wagon length and spaces between wagons.

## ASSESSING THE EFFICIENCY OF THE FLEET OF RUSSIAN RAILWAYS JSC BASED ON PERFORMANCE IN 2015–2024

To determine the efficiency of the existing wagon fleet, we analysed statistical data of Russian Railways JSC[1] [11] on the average static load of wagons $\bar{P}_{st}$ and the average load capacity utilisation rate $\bar{\lambda}$.

The statistical data of Russian Railways JSC define the average static load of wagon as a ratio of the weight of goods $Q$ loaded on networks of Russian Railways or an individual line and the number of wagons loaded $N$:

$$\bar{P}_{st} = \frac{Q}{N},$$

[1] Report on loading of all wagon accessories and the use of their carrying capacity when transporting all goods. RZhD OJSC FGO-10A. Moscow: Main Computer Centre of RZhD OJSC, 2024.

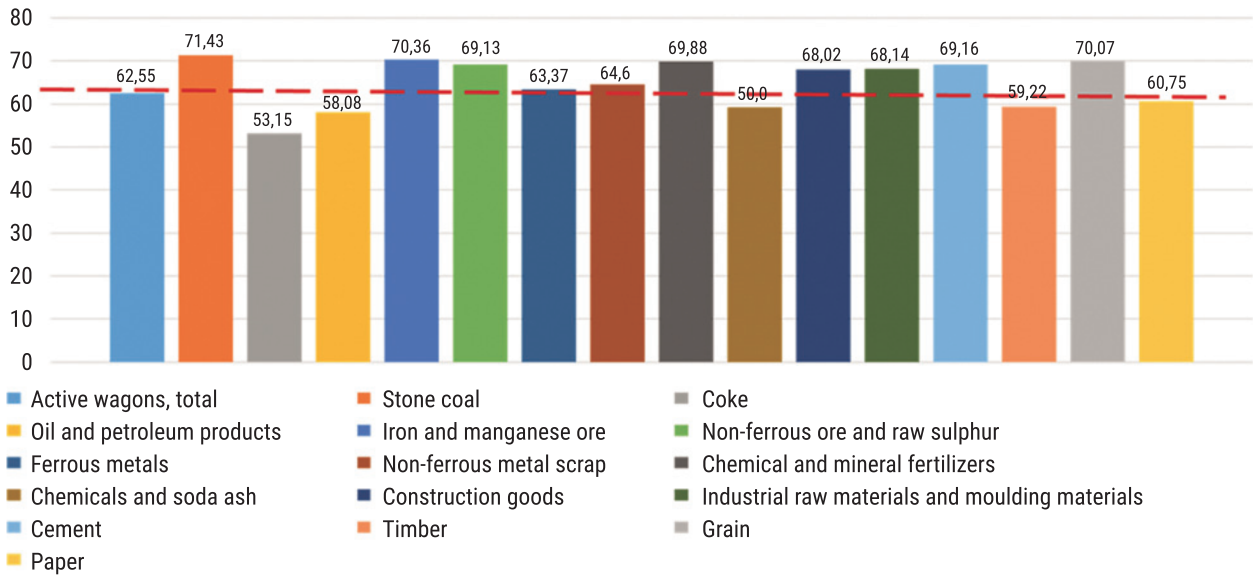


**Fig. 1.** Static load per wagon in 2024

or by type of goods

$$\bar{P}_{st\,i} = \frac{Q_i}{N_i},$$

where $Q_i$ is the weight of loaded goods of type $i$; and $N_i$ is the number of wagons loaded with goods of type $i$.

The average load capacity $\bar{P}$ is determined as a ratio of the sum of the nominal load capacity of wagons available for loading and the number of wagons loaded. The load capacity utilisation rate is determined as a ratio of the average static load and the average load capacity

$$\lambda = \frac{P_{st}}{P} \text{ or } \lambda_i = \frac{P_{sti}}{P_i}.$$

*Table 1* and *Fig. 1* and *2* show data on static load of wagons and the utilisation of their load capacity when transporting basic bulk goods on Russian railways in 2015 and 2024. The average load capacity of a wagon increased from 68.1 tonnes to 69.9 tonnes.

*Table 1*

**Static load and utilisation of load capacity of freight wagons in 2015 and 2024**

| Group of goods | Wagon static load, t | | Wagon load capacity utilisation, % | |
|---|---|---|---|---|
| | 2015 | 2024 | 2015 | 2024 |
| Active wagons, total | 61.38 | 61.97 | 90.1 | 88.7 |
| Stone coal | 69.2 | 71.5 | 98.3 | 98.8 |
| Coke | 45.45 | 53.97 | 69.3 | 76.1 |
| Oil and petroleum products | 58.24 | 58.23 | 91.6 | 90.3 |
| Iron and manganese ore | 70.58 | 70.64 | 98.5 | 99.0 |
| Non-ferrous ore and raw sulphur | 67.49 | 68.91 | 97.1 | 98.3 |
| Ferrous metals | 60.97 | 63.47 | 87.5 | 90.3 |
| Non-ferrous metal scrap | 63.16 | 64.87 | 93.3 | 93.8 |
| Chemical and mineral fertilizers | 67.63 | 70.57 | 96.4 | 98.0 |
| Chemicals and soda ash | 56.75 | 60.46 | 90.9 | 92.4 |
| Construction goods | 65.87 | 68.01 | 95.4 | 96.5 |
| Industrial raw materials and moulding materials | 65.85 | 67.23 | 95.8 | 96.4 |
| Cement | 69.11 | 69.58 | 97.0 | 96.9 |
| Timber | 56.54 | 59.44 | 84.0 | 87.3 |
| Grain | 64.95 | 71.18 | 92.4 | 97.0 |
| Paper | 56.81 | 61.77 | 84.0 | 91.2 |

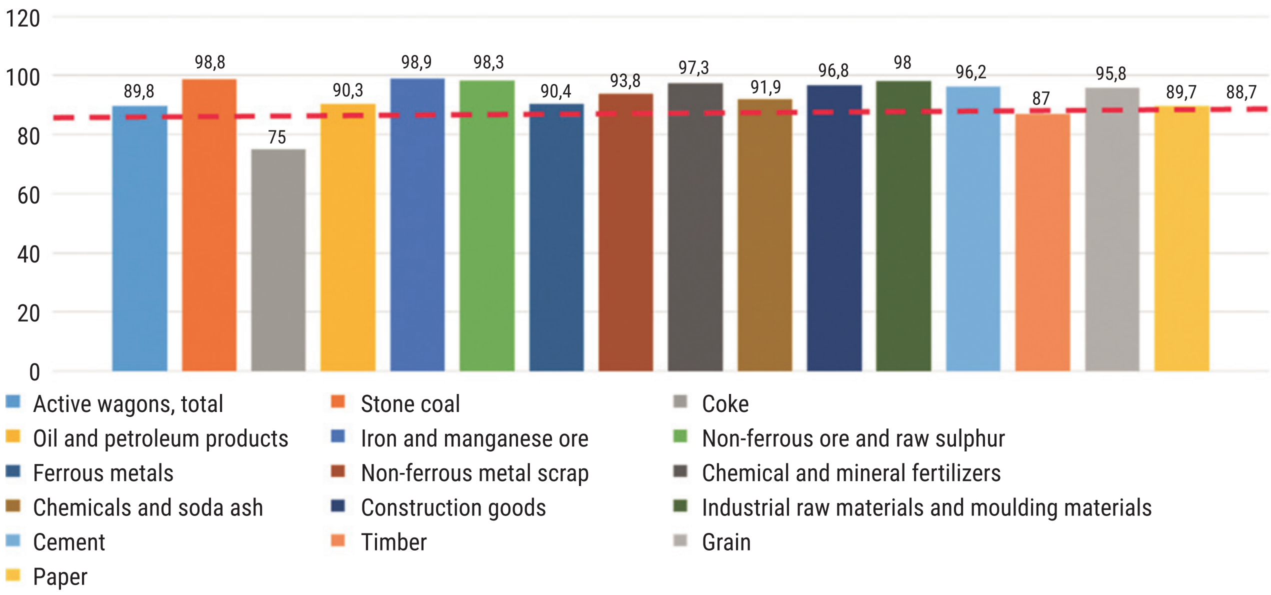


**Fig. 2.** Wagon load capacity utilisation rates in 2024

An analysis of this data allows us to conclude that the load capacity of gondola wagons is almost fully utilised when transporting coal and ore (underloading is below 2%). The average static load for hopper wagons when transporting chemicals and mineral fertilizers is also close to the average load capacity, with underloading of 2%. The static load of wagons is minimal when transporting:

- Coke: 53.97 tonnes;
- Chemicals and soda ash: 60.46 tonnes;
- Timber: 59.44 tonnes;
- Paper: 61.77 tonnes;
- Ferrous metals: 63.47 tonnes;
- Oil and petroleum products: 63.6 tonnes.

For other goods, the static load is close to the carrying capacity. Although more than 200,000 new innovative freight wagons with an axle load of 25 tf have been added to the network fleet over the last ten years, there has been no significant growth in the average load capacity (+2.6%) or the average static load across the freight wagon fleet (+0.96%), while the capacity utilisation has become even lower (–1.5%). This suggests that the cubic capacity is insufficient, preventing wagons from being loaded to their full capacity.

## ANALYSIS OF THE IMPACT OF "T" – LOADING GAUGE WAGONS ON THE TRANSPORTATION PROCESS AND CARRYING CAPACITY

In our opinion, for the static load of wagons to be substantially increased, we should both increase their load capacity by switching to an axle load of 25 tf, and increase the transverse dimensions of wagons by using the "T" — loading gauge wagons and reducing their length. This will lead to an increase in the net linear load of trains, thus increasing their carrying capacity. What is particularly important is that this approach to increasing the carrying capacity will allow attracting private capital and somewhat reducing the need for government investment.

The task of preparing railways for the introduction of "T" — loading gauge wagons was set by the USSR Ministry of Railways in its Order No. 22/Ts "On Preparing Railways for the Introduction of Oversized Wagons with Increased Axle and Linear Loads" as early as May 3, 1982. The Order provided for completing the required reconstruction of the network over a period of 20 years. Unfortunately, it remained unimplemented; however the work to bring railways in line with the "C" — obstruction clearance requirements is still underway [11].

What effects can be achieved through the introduction of rolling stock with "T" — loading gauge wagons under the current conditions?

In order to assess the effect on the transportation process, the effects of the introduction of "T" — loading gauge wagons for the government, carriers, and operator companies are considered below.

*Fig. 3* shows comparison of rolling stock gauge areas.

The use of the "T" — loading gauge wagons will increase the cross-sectional area of the wagon by approximately one square metre or approximately 10%. This will allow for building wagons with improved technical and economic parameters and increasing the carrying capacity of railways.

The main characteristics of the most common types of prospective wagons with the "T" — loading gauge wagons are shown in *Fig. 4–6*. The length of a gondola

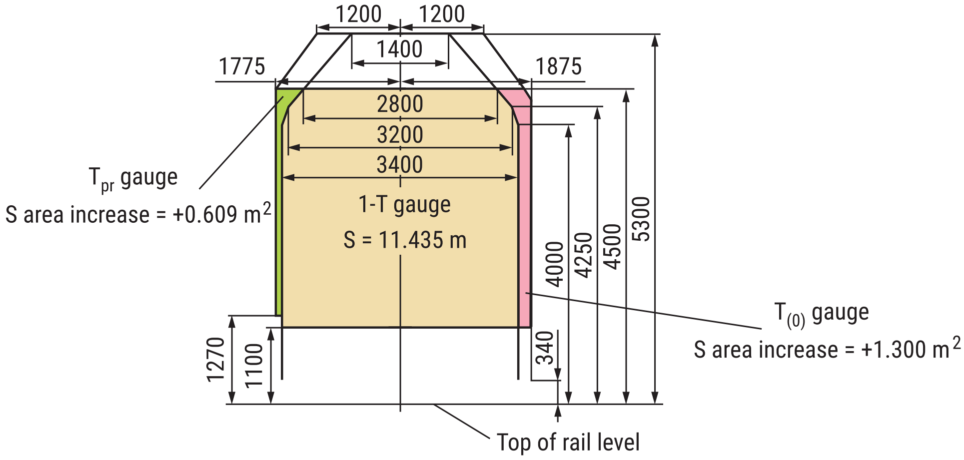


**Fig. 3.** Comparison of 1T, $T_{pr}$, and "$T_a$" — loading gauge wagons

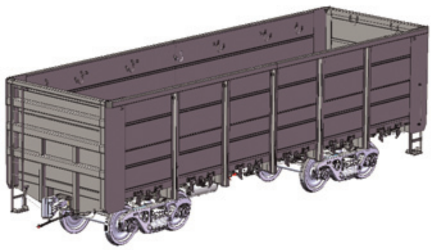

**Fig. 4.** Potential "T" — loading gauge wagons gondola wagon: Load capacity: 76 t; tare weight: 24 t; cubic capacity: 94 $m^3$; coupled length: 11,895 mm; maximum width: 3,540 mm; linear load: gross: 8.4 t/m, net: 6.4 t/m

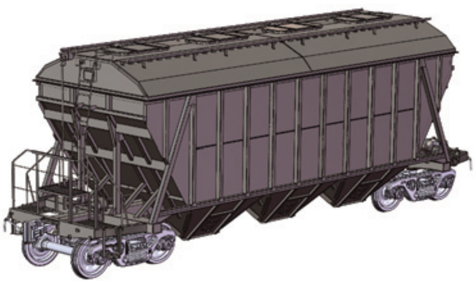

**Fig. 5.** Potential "T" — loading gauge wagons hopper wagon: Load capacity: 79 t; tare weight: 21 t; cubic capacity: 111–120 $m^3$; coupled length: 13,050 mm; maximum width: 3,570 mm; linear load: gross: 7.66 t/m, net: 6.03 t/m

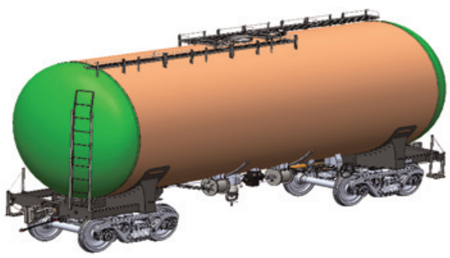

**Fig. 6.** Potential "T" — loading gauge wagons tank wagon for light petroleum products: Load capacity: 75 t; tare weight: 25 t; cubic capacity: 108 $m^3$; coupled length: 12,020 mm; maximum width: 3,580 mm; linear load: gross: 8.32 t/m, net: 6.23 t/m

wagon will be reduced by the length of the standard hatch, and its width will be increased by 322 mm. The length of a hopper wagon will be reduced by 1,470 mm, and its width will be increased by 320 mm. The length of a tank wagon will remain unchanged to enable loading and unloading at the existing loading and unloading racks, and its width will be increased by 315 mm. The cubic capacity of all three wagon types will increase. The increases in the train weight due to the use of these wagons are shown in *Table 2*.

## INCREASING THE CARRYING CAPACITY OF RAILWAYS: PROSPECTS OF INTRODUCTION OF "T" — LOADING GAUGE WAGONS

Increasing the weight of trains by 6% (for tank wagons) to 17% (for gondola wagons) allows us to conclude that there is a potential for increasing the carrying capacity of railways and improving the efficiency of transportation.

- It is reasonable to link the design and introduction of "T" — loading gauge wagons with increasing the load capacity of wagons for transportation of oil and petroleum products, coke, paper, chemicals and soda ash, timber, and metals at an axle load of 25 tf. The transition to the "T" — loading gauge wagons will provide economic effects both for Russian Railways JSC and other transport market players.
- Without increasing the load capacity, shorter "T" — loading gauge wagons will enable Russian Railways JSC to increase the train weight to 7.600–8.300 tonnes, thereby increasing the carrying capacity by 11–17 %, reducing the required wagon fleet size, and reducing costs on traction and infrastructure maintenance. Both Russian Railways and the country as a whole will benefit from the implementation of this project. Owners, consignors, and manufacturers of wagons will not get any effect.

*Table 2*

**Train weight increases due to reduced wagon length when using "T" — loading gauge wagons under GOST 9238-2022**

| Parameter | General-purpose gondola wagon | | Oil tank wagon | | Grain hopper wagon | |
|---|---|---|---|---|---|---|
| | "T" – loading gauge wagons | Comparison with model 12-196-02 UVZ, loading gauge 1-T | "T" – loading gauge wagons | Comparison with model 15-9993 OVK, loading gauge 1-T | "T" – loading gauge wagons | Comparison with model 19-1299 RM Rail, loading gauge 1-T |
| Wagon tare weight, t | 24.0 | 24.5 ± 0.5 | 25.0 | 25.5–26.7 | 21.0 | 21.0 |
| Load capacity, t | 76.0 | 75.0 | 75.0* | 68.6* | 79.0 | 79.0 |
| Axle load, t/axle | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Cubic capacity, m$^3$ | 94.0 | 94.0 | 98.0 | 88.0 | 111.0...120.0 | 111.0 |
| Net linear load, t/m | 6.4 | 5.39 | 6.23 | 5.62 | 6.05 | 5.44 |
| Gross linear load, t/m | 8.4 | 7.18 | 8.32 | 7.87 | 7.66 | 6.88 |
| Distance between bogie centres, mm | 6,940 | 8,650 | 7,800 | 7,800 | 9,240 | 10,300 |
| Coupled length, mm | **11,895** | **13,920** | **12,020** | **12,020** | **13,050** | **14,520** |
| Maximum outer width, mm | 3,510 over posts | 3,198 over posts | ∅3,580 | ∅3,265 | 3,570 | 3,250 |
| Interior dimensions, mm | Length 11,000<br>Width 3,296<br>Height 2,590 | Length 13,030<br>Width 2,958<br>Height 2,436 | ∅3,560 | ∅3,240 | – | – |
| ATR (above top of rail) height, mm | 3,980* | 3,866 | 5,157 | 4,797 | 4,840 | 4,910 |
| Weight of a 71-conventional wagon train (994 m) | **8,300** | **7,100** | **8,200*** | **7,085*** | **7,600** | **6,800** |

* — when transporting petrol.

Given the expected effect from the use of "T" — loading gauge wagons, in 2024, RM Rail had negotiations with major operator companies to identify possible routes for operating "T" — loading gauge wagons freight wagons taking into account the existing limitations for loading and unloading on non-public tracks. As a result, the following prospective routes were identified:

- For gondola wagons:

Erunakovo, West Siberian Railway – Luzhskaya, October Railway;

Kostomuksha, October Railway – Koshta, Northern Railway;

Erunakovo, West Siberian Railway – Nakhodka Vostochnaya, Far Eastern Railway;

- For tank wagons:

Limbey, Sverdlovsk Railway – Luzhskaya, October Railway;

Stenshino, Moscow Railway – Luzhskaya, October Railway;

Afinskaya, North Caucasus Railway – Novorossiysk, North Caucasus Railway.

In response to an enquiry as to whether "T" — loading gauge wagons can be operated on these routes, the Directorate for Infrastructure Diagnostics and Monitoring stated that the proposed routes have 427 barrier sites on the October, Moscow, Northern, Gorky, East Siberian, and Far Eastern Railways, where they can only run on adjacent tracks subject to speed restrictions.

Because of 227 barrier sites within the limits of the North Caucasus, South Ural, Sverdlovsk, Krasnoyarsk and Transbaikal Railways, it will not be possible to operate "T" — loading gauge wagons wagons on these lines until 2036.

It is currently possible to launch the operation of "T" — loading gauge wagons on the lines Kostomuksha, October Railway–Koshta, Northern Railway and Stenshino, Moscow Railway–Luzhskaya, October Railway for gondola wagons and tank wagons, respectively.

The second problem is related to an increased linear load of the proposed "T" — loading gauge wagons.

According to the Guidelines for Handling of Rolling Stock on Railway Bridges of Russian Railways JSC, the permissible linear load for Category IV bridges is 8.2 tf per m of track with an axle load of up to 27 tf.

The permissible linear load for Category V bridges is even smaller and is determined by calculation.

This is the second problem to be addressed. A number of professionals [12, 13] believe that under certain conditions the permissible linear load could be increased to 9 tf/m.

According to the Directorate for Infrastructure Diagnostics and Monitoring, RUB 56 billion in investment is required to address the barriers on the routes suitable for the operation of "T" — loading gauge wagons. The amount may seem to be huge, but it accounts for just 7% of the costs spent by Russian Railways to modernise its infrastructure over the last two years.

## CONCLUSION

To summarize the above discussion on the prospects of creation and problems of introduction of "T" — loading gauge wagons, we can conclude that the following benefits will follow from the introduction of wagons with an increased capacity and higher load capacity:

- Railways will benefit from reduced traction costs, required operating fleet, and reduced en-route maintenance costs;
- Wagon owners will receive new, more efficient wagons and benefit from reduced repair costs;
- Operators will benefit from reduced costs of operation and light running;
- Consignors will benefit from reduced shipping costs;
- Wagon manufacturers will benefit from a consistent demand for the renewal of the existing fleet;
- The government will be able to reduce investment in increasing railway capacity.

Unfortunately, the updated Strategy for Scientific and Technical Development of Russian Railways Holding Company until 2025 and in the Future up to 2030 (White Paper)[2] does not mention overcoming barriers to the introduction of the "T" — loading gauge wagons or increasing the permissible linear load on artificial structures among the objectives for the development of facilities and technologies for heavy-haul traffic management. Given the efficiency of "T" — loading gauge wagons, we suggest recommending administrations of 1,520 mm gauge railways to pay particular attention, when expanding operating domains for heavy-haul trains, to the fact that these lines need to be brought in line with the "C" — obstruction clearance structure requirements and the permissible linear load should be increased to at least 8.4 t/m.

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# Overview and analysis of instrumented wheelset designs

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ABSTRACT The article provides an overview and analysis of the designs of instrumented wheelsets used to measure lateral, longitudinal and vertical forces at the point of contact between the wheel and the rail. The use of instrumented wheelsets is an important tool for conducting research and certification tests on rolling stock. The relevance of this tool increases with higher axle loads and higher speeds. In addition, the instrumented wheelsets currently in use allow for the implementation of various (piecewise continuous or continuous) methods for recording vertical and lateral interactive forces in the wheel-rail system in a single turn of a wheel. Point methods of measuring the impact of rolling stock on the railway track by deformation in the rail allow for measuring the force between the wheel and the rail only at the moment when the wheel is above the measuring section of a railway track. The main disadvantage of using existing instrumented wheelsets for estimating the condition of a railway track is that measurements depend on the speed of movement and the discreteness of the measuring equipment. When using an instrumented wheelset for assessing the condition of a railway track, the probability of detecting a section of the track that presents a risk of derailment is not high enough and needs to be increased.

Methods: A retrospective analysis of the use of instrumented wheelsets was conducted; the main stages of the evolution of instrumented wheelsets were identified. The features of the designs of modern Russian and foreign instrumented wheelsets and methods for recording measurements of vertical and lateral forces acting between the wheel and the rail were considered.

Findings: Conclusions were made about the main directions of development and requirements for instrumented wheelsets. A description was provided for the design and characteristics of the instrumented wheelset with continuous measurement recording developed by scholars of PGUPS and NVC Vagony JSC, which features the lowest measurement pitch among the currently known Russian systems and is provided with special software used to detect sections of the railway track that present the risk of derailment.

KEYWORDS: stress-strain state of the wheel plate; wheel-rail system; instrumented wheelset; diagnostics of railway track; continuous measurement recording; monitoring of technical condition

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*Научная статья*

# Обзор и анализ конструкций тензометрических колесных пар

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АННОТАЦИЯ Выполнен обзор и анализ конструкций тензометрических колесных пар, применяемых для измерения поперечных, продольных и вертикальных сил в точке контакта колеса и рельса. Использование тензометрических колесных пар — важный инструмент для проведения исследований и испытаний подвижного состава. Актуальность его применения возрастает при повышении осевых нагрузок и увеличении скоростей движения. Кроме того, применяемые в настоящее время тензометрические колесные пары позволяют реализовывать различные методы регистрации (кусочно-непрерывные, непрерывные) вертикальных и боковых сил взаимодействия в системе «колесо — рельс» за один оборот колеса. Точечные методы измерения воздействия подвижного состава на железнодорожный путь по деформациям, возникающим в рельсе, позволяют измерить силу между колесом и рельсом только в момент расположения колеса над измерительным сечением, расположенным на участке железнодорожного пути. Основным недостатком применения существующих тензометрических колесных пар для диагностики состояния железнодорожного пути является ограничение в шаге регистрации силового воздействия. Для диагностики состояния железнодорожного пути с использованием тензометрической колесной пары вероятность обнаружения сходоопасного участка пути недостаточно высока и возникает задача ее увеличения.

Выполнен ретроспективный анализ истории применения тензометрических колесных пар, определены основные этапы эволюции конструкций. Рассмотрены особенности конструкций современных отечественных и зарубежных тензометрических колесных пар и методы регистрации измерений вертикальных и боковых сил, действующих между колесом и рельсом.

Сделан вывод об основных направлениях развития и требованиях к тензометрическим колесным парам. Описана конструкция и характеристики тензометрической колесной пары с непрерывной регистрацией измерений, разработанной учеными ПГУПС и сотрудниками АО «НВЦ “Вагоны”», обладающей минимальным расстоянием шага регистрации силового воздействия из известных в настоящее время отечественных конструкций, а также специальным программным обеспечением, применяемым для обнаружения сходоопасных участков железнодорожного пути.

КЛЮЧЕВЫЕ СЛОВА: напряженно-деформированное состояние диска колеса; система «колесо-рельс»; тензометрическая колесная пара; диагностика состояния железнодорожного пути; непрерывная регистрация измерений; мониторинг технического состояния

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## INTRODUCTION

When designing and launching production of new rolling stock models, it is necessary to determine the forces acting at the contact point between the wheel and the rail. It is not difficult to calculate static loads at the contact point. But it is much more difficult to determine the forces arising from the dynamic interaction between the rolling stock and the rail. Measuring these interactive forces is crucial in safety certification and testing of new and upgraded high-speed rolling stock in Europe and many other countries. The European standard for testing is EN14363; the standard in use in the United States is 49 CFR 213. Russia has two fundamental methods for determining force action: by using strain gauge circuits located on the rails or an instrumented wheelset with strain gauges.

An instrumented wheelset (IWS) is a railway wheelset equipped with primary transducers and a data transmission system that uses a measuring and computing system to measure forces at the wheel-rail interface during movement.

## BRIEF HISTORY OF IWS USE AND DEVELOPMENT

In 1946, in the USSR, Mikhail F. Verigo proposed to perform continuous recording of forces exerted by the wheel on the rail by measuring vertical and horizontal components of the wheel-rail interaction forces using the stress state of the wheel plate [1].

The method of measuring forces using instrumented wheelsets became widely known after it was described in papers by Olson and Johnsson (1959, 1960) [2, 3]. Olson and Johnsson found that radial deformations of the wheel plate were very sensitive to lateral forces and almost insensitive to vertical forces. This allowed them to develop a method of continuous recording of lateral (horizontal, transverse) forces between the wheel and the rail by measuring radial deformations of the wheel plate and design instruments for statistical recording of the average force values.

In 1962, the Electro Motive Division (EMD) of General Motors (GM) created an instrumented wheelset on a locomotive with the measuring equipment that measured lateral force proportional to the average deformation of the wheel plate [4]. Vertical wheel load data was obtained using sensors installed through holes drilled in the wheel plate. The arrangement enabled obtaining a peak signal proportional to the vertical wheel load per revolution. The wheelset was recalibrated in 1968 and was in use until 1972.

In Japan and the United Kingdom, methods for measurement of forces using a arm wheel-based IWS have been developed and refined since 1952 [5]. The greatest contribution to the development of arm wheel-based IWS was made by the British Railways in the 1970s and 1980s [6]. In these instrumented wheelsets, strain gauge sensors are positioned on certain sections

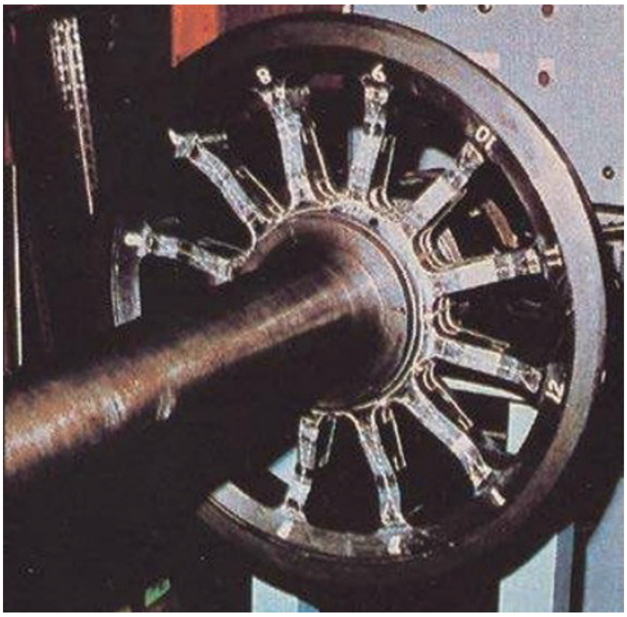


**Fig. 1.** Arm wheel-based IWS [6]

of the spokes (*Fig. 1*) and connected into bridge circuits. The advantage of this method of measurement is that it provides better sensitivity to vertical force due to higher vertical elasticity. Its main drawback is that machining of spokes is very complicated and expensive and requires high precision. Currently, this method is occasionally used in the United Kingdom and Switzerland [7].

Depending on the position of sensors, there are two types of instrumented wheelset designs: with sensors placed on the axle or on the plate. Instrumented wheelsets with sensors on the axle appeared in the early 1970s. They are based on measuring bending and torsional moments in particular cross-sections of the axle. By measuring bending moments in cross-sections it is possible to estimate approximate vertical and transverse forces on the wheels, with neglect of wheelset mass forces. By also measuring two torsional moments, it is possible to calculate the approximate longitudinal forces. Thus, six forces — two longitudinal, two transverse, and two vertical forces — can be determined from the six moments measured. *Fig. 2* shows a diagram of an instrumented wheelset for measuring bending and torsional moments. Bending moments and torques are measured using strain gauge bridges. Signals are transmitted to the axle via slip rings installed in one of the stub axles of the axle or by radio.

At first sight, the principle of measuring moments and torques of the axle seems quite simple, effective, and precise. Another advantage is that the wheels on the measuring axle can be replaced.

However, the method has two main drawbacks [8].

- Forces can be applied to the wheel in different positions. Since the position of the contact point may change, the position of the vertical force application point will change, too. A change in the position will change the moments measured on the axle, thereby introducing errors that cannot be compensated for, as the actual position where the force is applied is unknown.
- Axle moments depend on the unsprung mass of the axle and other unsprung parts of the wheelset. Thus, it is impossible to fully assess the impact of the unsprung mass on vertical forces.

These drawbacks hamper the use of IWS with sensors on the axle.

In 1973, EMD developed a new instrumented wheelset that used sensors in other positions to minimize the effects of lateral orientation of the wheel/rail on the lateral output, and some new wiring schemes. The strain gauge bridge was configured to make its output sensitive to symmetric bending [10].

In 1973, FRA made a contract with the Association of American Railroads (AAR) to use four CK-36 cast steel wheels of the 100-tonne Barber S-2 bogie for measuring lateral and vertical forces [11]. The wheelsets continuously measured lateral forces, but vertical load measurements were limited by the spatial resolution of one-quarter of the wheel circumference.

The Canadian National Research Centre developed an instrumented wheelset using standard disc plate wheels, however they used cast, rather than forged, wheels. This was done to achieve a uniform 1/16 inch thickness of the wheel, which is greater than that of forged wheels [12].

Both General Electric on its U30C locomotive [13] and EMD on its SPD-40 used instrumented wheelsets with radially oriented strain gauges in separate bridge circuits that only received a signal within a narrow arc of maximum sensitivity. On these locomotives, only one IWS was used, usually placed as the drive axle of either the leading or trailing bogie of the locomotive.

In 1976, Amtrak tested the Rc4A locomotive built by ASEA using two instrumented wheelsets on a single bogie to read signals of vertical and lateral wheel-rail contact forces, as well as lateral wheel-bogie contact forces.

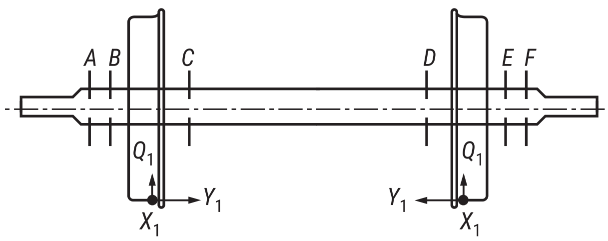


**Fig. 2.** IWS with sensors located on the axle [9].
*A*, *B*, *C*, *D*, *E*, *F* are cross-sections at which measuring sensors are installed

FRA concluded a contract with ENSCO Inc. to build an instrumented wheelset on a locomotive where each wheel had two vertical and two lateral measuring bridges. Vertical bridges consisted of strain gauges installed on both upper and lower parts of the holes drilled through the wheel plate, similar to EMD wheelsets [14]. The wheelset was used for testing Amtrak's SPD-40F train in 1977 [15].

In 1977, Amtrak and FRA purchased three instrumented wheelsets in Sweden. ASEA AB, Sweden, collaborated with the Swedish State Railways to build instrumented wheelsets. Continuous measurement of vertical force was achieved by combining two triangular waveforms [16]. These wheelsets were used by FRA for tests at the Transportation Test Center (EEC) in Pueblo, Colorado, in November–December 1978.

Paper [17] reported on experimental studies where the sensitivity of measurement of vertical force was increased by providing small "dummy spokes" by drilling the wheel plate close to the rim, where strains are low.

## OVERVIEW OF CURRENT FOREIGN IWS DESIGNS

TÜV SÜD has developed the fifth-generation instrumented wheelset, IWT5 (*Fig. 3*), featuring numerous advantages over IWT4. They used a standard wheelset without any modification. This means that no special test wheels need to be manufactured, simplifying logistics, reducing the time required to produce IWS, mitigating risks, and reducing costs of testing. IWT5 allows for measuring all (vertical, transverse, and longitudinal) forces simultaneously in all three directions. Vertical and transverse forces are important for assessing dynamic characteristics of rolling stock and the track condition, while longitudinal forces are essential for assessing the wear of the contact area.

What distinguishes IWT5 from other solutions is its unique telemetry system. The fifth-generation telemetry system has increased performance and robustness while also using a "plug and play" architecture that allows for fast replacement of elements. The main benefit of using the telemetry system is that there is no need for slip-ring devices, improving the reliability and simplifying the installation of the system as IWT5 is using an inductive telemetry system designed specifically for railway transport. This helps avoiding electromagnetic interference problems that are normally typical of radio-based telemetric systems. IWT5 does not need additional batteries, as an advanced inductive power transfer system ensures IWT5 is powered whenever the vehicle is turned on. Technical specifications of IWT5 are listed in *Table 1*.

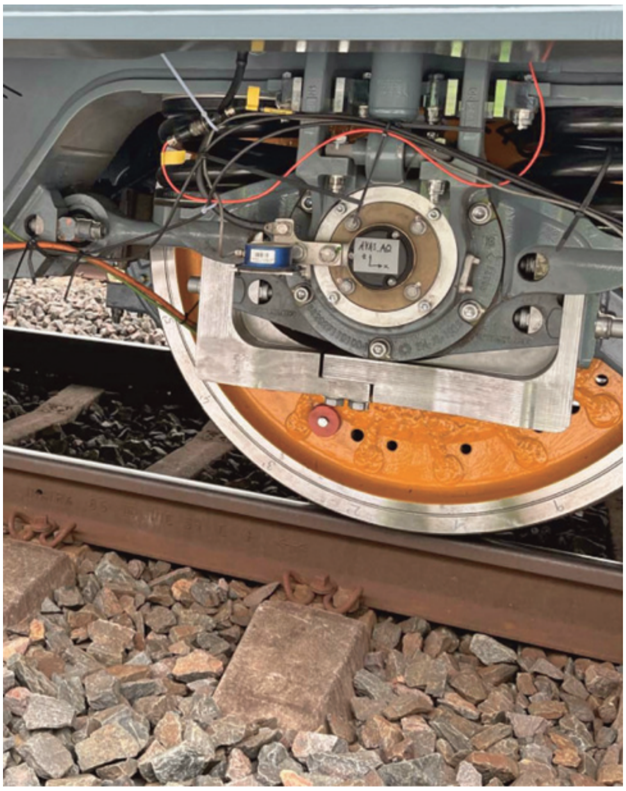

**Fig. 3.** IWT5 instrumented wheelset from TÜV SÜD, Germany[1]

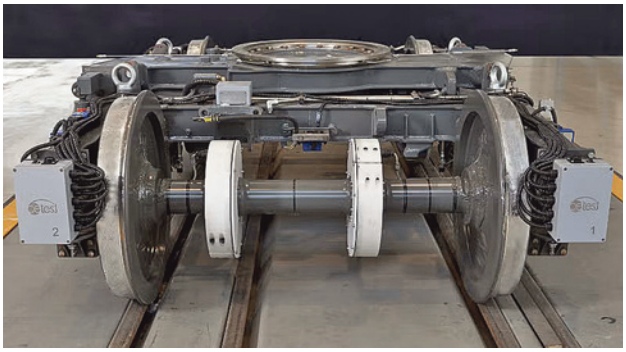

**Fig. 4.** Instrumented wheelset from CETEST, Spain[2]

Test center, CETEST, Spain, presented a proprietary IWS system (*Fig. 4*). It allows for measuring vertical, transverse, and longitudinal forces in real time with the measurement uncertainty of 4%. The sampling rate

[1] Instrumented wheelset technology IWT 5. [Electronic media]. — URL: https://www.tuvsud.com/en/-/media/global/pdf-files/brochures-and-infosheets/rail/220830_tuv_sud_iwt5_infosheet_final.pdf (дата обращения: 11.03.2025).
[2] Railway technology. Instrumented Wheelset. URL: https://www.railway-technology.com/products/instrumented-wheelset/

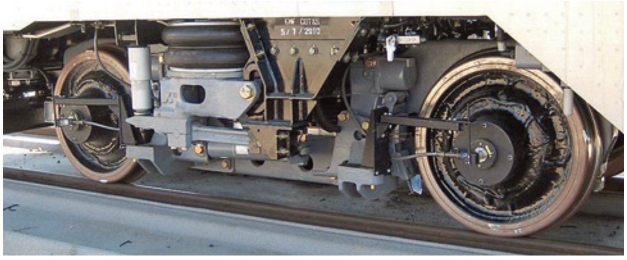

**Fig. 5.** Instrumented wheelsets from ENSCO, USA, on a bogie[3]

is up to 1 kHz. The IWS can identify the wheel-rail contact point position and provides compensation for errors (signal drift, thermal effects, rotation effects, and interferences). Communication is provided by optical telemetry systems without batteries.

ENSCO, USA, has been manufacturing and using its own proprietary IWS since 1975 (*Fig. 5*). ENSCO's IWS systems are designed to measure vertical, transverse, and longitudinal forces at the wheel-rail contact point in real time, along with the contact location.

## OVERVIEW AND ANALYSIS OF RUSSIAN INSTRUMENTED WHEELSET DESIGNS

Several IWS systems have been designed in Russia to date. These allow for up to eight measurements per wheel revolution and record only two components of the force interaction between the wheel and the rail: vertical and lateral forces, as distinguished from their foreign counterparts providing the possibility of recording longitudinal forces and determining the coordinates of the contact area in the wheel-rail system, which improves the accuracy of measurement [18].

Paper [19] notes that IWS systems developed in Russia differ by the location of the measurement circuits (the outer or inner side of the wheelset plates) and the number of strain gauges used for arranging measurement circuits with different angular intervals. Depending on the arrangement, IWS can produce a continuous function of interaction forces with the measuring resolution of 0.18 m to 0.75 m. The smaller the resolution, the more strain gauges and measuring circuits are required, which makes the device too complicated and detrimentally affects its reliability, manufacturing complexity, maintenance, and repair.

An IWS developed by VNIKTI JSC (*Fig. 6*) [20] is provided with LY11-10/350 strain gauges manufactured by HBM, Germany, with a measuring grid length of 10 mm and nominal resistance of 350 Ohm. To measure vertical and lateral forces, the strain gauges are glued to the inner sides of the wheel plates and connected to a half-bridge circuit. Two groups of circuits are used to determine vertical and lateral forces in a single line; each line is positioned at 90° to the other, thus enabling point measurements of vertical and lateral forces [21].

PGUPS and NVC Vagony JSC developed an instrumented wheelset with strain gauges positioned on two concentric diameters of the inner side of the wheel plate at a pitch of 22.5° along the circular arc (a total of 64 half-bridge circuits of strain gauges). The IWS ena-

*Table 1*

**Technical specifications of IWT5**

| Specifications | Value |
|---|---|
| Vertical and transverse force measurement uncertainty | Less than 3% at 20 Hz |
| Frequency of longitudinal force measurement | Over 10 Hz |
| Contact point position measurement accuracy | Typically ± 2 mm. Accuracy is degraded in two-point contact conditions |
| Capabilities for handling two-point contact forces | Equivalent global values for the contact forces. Individual contact forces for individual points of contact are not measured |
| Operating temperature | −25 °C to +50 °C |
| Permissible test speed | 4,500 km/h |
| Output interfaces | Analogue connections BNC or D-Sub, EtherCAT, CAN, TCP/IP, digital interfaces for imc Cronos and HBK Quantum X. Other interfaces are available on customer demand |
| Compatibility | P32 Telemetry System, PROSE IWT |

[3] ENSCO. Official web-site. URL: https://www.ensco.com/rail/instrumented-wheel-sets-iws

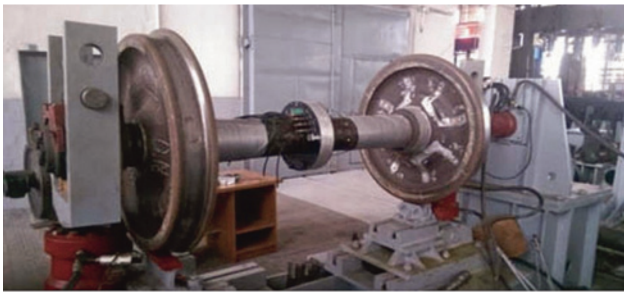

**Fig. 6.** Instrumented wheelset of VNIKTI JSC on a test bench [24]

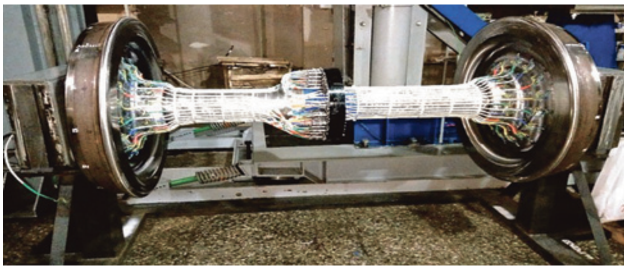

**Fig. 7.** Instrumented wheelset of PGUPS and NVC Vagony JSC

bles the implementation of the piecewise continuous method for recording of vertical and lateral forces in the wheel-rail system with a minimum pitch of 190 mm per wheel revolution (*Fig. 7*) [22].

Patent No. 2682567 for "Data collection device and method for assessing the results of wheel-rail interaction" [23] was obtained in 2017, and a prototype instrumented wheelset was produced in 2018. The developed IWS was tested on the high-speed test site of the Railway Research Institute (VNIIZhT) on the Belorechenskaya–Maikop railway section during the dynamic performance tests and the track impact tests of 12-9548-01 heavy-haul open wagons on 18-6863 bogies with an axle load of 27 tonnes on the Smychka–Kachkanar railway section.

This pitch of force recording is sufficient when it comes to testing rolling stock for analysing the forces arising during traveling at different speeds on representative sections of a railway track. However, there is a technical solution for the creation of a digital software and hardware platform for monitoring the technical condition of a railway track using IWS [24]. When using these IWS systems to assess the condition of a railway track, the probability of detecting a section of track that presents the risk of derailment is not sufficiently high and needs to be increased.

To address this problem, scholars of Emperor Alexander I St. Petersburg State Transport University and NVC Vagony JSC developed an instrumented wheelset with the lowest pitch among the currently available Russian IWS designs. It enables continuous recording of forces [25]. When the distances between the measuring sections at which strain gauges are located are reduced, the accuracy of measurement increases, and this can significantly increase the probability of detecting a section of track with the risk of derailment. Dynamic processes in the wheel-rail system can be recorded at a predetermined distance per wheel revolution. Therefore, the use of the IWS with continuous recording of dynamic processes makes it possible to detect dangerous defects in railway track.

Special-purpose C#software was developed for monitoring the technical condition of a railway track by the IWS with continuous recording. It uses GPS navigation to determine precise geo-coordinates of the identified track sections with the risk of derailment, generates and stores large amounts of recorded data, including geo-coordinates, and relies on modern big-data and cloud-computing capabilities for real-time computer-aided data processing, enabling identification of track sections with the risk of derailment.

## CONCLUSION

The above overview and analysis have shown that instrumented wheelsets allow for measurements in a broad range of operating conditions, but have certain drawbacks, such as the complexity and high cost, the need for preliminary calibration of wheelsets, and impossibility to account for changes in the geometry of the wheel tread during operation.

The main challenge in measuring the wheel-rail contact forces is that wheel deformations are caused not only by the lateral, longitudinal and vertical forces being measured, but are also influenced by various other parameters. Apart from the forces, wheel deformations during movement are also caused by the varying position of the contact point, wear of the wheel profile, the angular velocity of the wheel, and changes in temperature. Taking into account the influence of all these parameters is a major prerequisite for developing a method for measuring the wheel-rail contact forces and achieving a high accuracy of measurement.

Over the more than 65-year-long period of IWS systems existence we can identify several key periods of their development. It can be stated that the evolution of IWS follows a few main lines:

- Increasing structural capabilities. For example, modern IWS can not only measure all vertical, transverse, and longitudinal forces simultaneously in all three directions, but also determine the position of the wheel-rail contact point;
- Increasing the signal transmission speed by introducing optical telemetry systems;
- Improving the accuracy of measurement through the use of improved signal processing algorithms;

- Increasing self-sufficiency of IWS without the use of batteries by special power transfer systems, etc.

The instrumented wheelset for continuous measurement with the specialized software developed by PGUPS and NVC Vagony JSC can be used for assessing the condition of railway tracks and can significantly increase the probability of detecting track sections that present the risk of derailment.

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# History of the development of the Department of Technosphere and Environmental Safety and its contribution to improving occupational safety in railway transport

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ABSTRACT Objective: The purpose of this paper is to trace the formation and development of the Department of Technosphere and Environmental Safety over 75 years of its existence and assess the contribution of its staff to the development of the science of occupational safety, environmental protection, and the training of occupational health and safety specialists for Russian enterprises. Materials and methods: Archival documents of PGUPS and activity reports of the Department were reviewed. Findings: For the first time, this paper presents the stages of the Department's formation, from an associate professorship in safety engineering and fire safety equipment to a department with highly qualified personnel, material resources and technologies for solving challenging scientific problems and high-quality training of students. Practical significance: Based on the study of archival materials, memoirs of the Department's long-timer members, and reports, the stages of the Department formation were reconstructed. The collected materials allow for preserving the memory of the employees who made the greatest contribution to the development of the Department, its scientific activity and scholarly works. The contribution of the Department to the training of qualified university graduates is assessed.

KEYWORDS: technosphere safety; occupational safety specialist; environmental engineering

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*Обзорная статья*

# История развития кафедры «Техносферная и экологическая безопасность» и ее вклад в повышение безопасности труда на железнодорожном транспорте

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АННОТАЦИЯ Цель статьи — проследить становление и развитие кафедры «Техносферная и экологическая безопасность» на протяжении 75 лет ее существования, оценить вклад коллектива кафедры в развитие науки о безопасности труда, защите окружающей среды, в подготовку специалистов по охране труда для предприятий России. Рассмотрены архивные документы ПГУПС, отчеты кафедры о проделанной работе.

Впервые представлены этапы становления кафедры от доцентуры техники безопасности и противопожарной техники до кафедры, обладающей высококвалифицированными кадрами, материальной базой и технологиями для решения серьезных научных задач и качественного обучения студентов. На основе изучения архивных материалов, воспоминаний ветеранов кафедры, отчетов восстановлены этапы становления кафедры. Собранные материалы позволяют сохранить память о сотрудниках, внесших наибольший вклад в ее развитие, о разработках и научных трудах кафедры. Оценен вклад в дело подготовки квалифицированных выпускников университета.

КЛЮЧЕВЫЕ СЛОВА: техносферная безопасность; специалист по охране труда; инженерная защита окружающей среды

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## INTRODUCTION

In the post-WWII period, as the Soviet Union was recovering from the ruins, building new railways and reconstructing old ones, the country's higher education institutions for transport faced the challenge of training engineers who would not only master the art of building and operating railways, but also know how to do it in a safe way.

In January 1949, the Fire Safety Equipment associate professorship[1] was reorganized into the Safety Engineering and Fire Safety Equipment associate professorship[2]. In June of that year, Order No. 63/R for the Leningrad Order of Lenin Institute of Railway Engineers[3] issued in pursuance with Order No. 479 of the Ministry of Higher Education of the USSR dated April 26, 1949 reorganized the Safety Engineering and Fire Safety Equipment associate professorship into a similarly named department. Associate Professor Alexey E. Lemmergidt was appointed the head of the Department. Within a short period of time, by the start of classes in September 1949, the Department was staffed with full-time faculty members. During the 1949/50 academic year, the department was equipped with laboratory stands for the main sections of the course. The Safety Engineering and Fire Safety Equipment course was delivered in accordance with programmes approved by the Ministry of Higher Education and compulsoripy completed with an examination. The same order mandated that the Department should be involved in the graduation project process and work of state examination committees and that a graduation project not endorsed by a consultant in Safety Engineering and Fire Safety Equipment would not be eligible for defence.

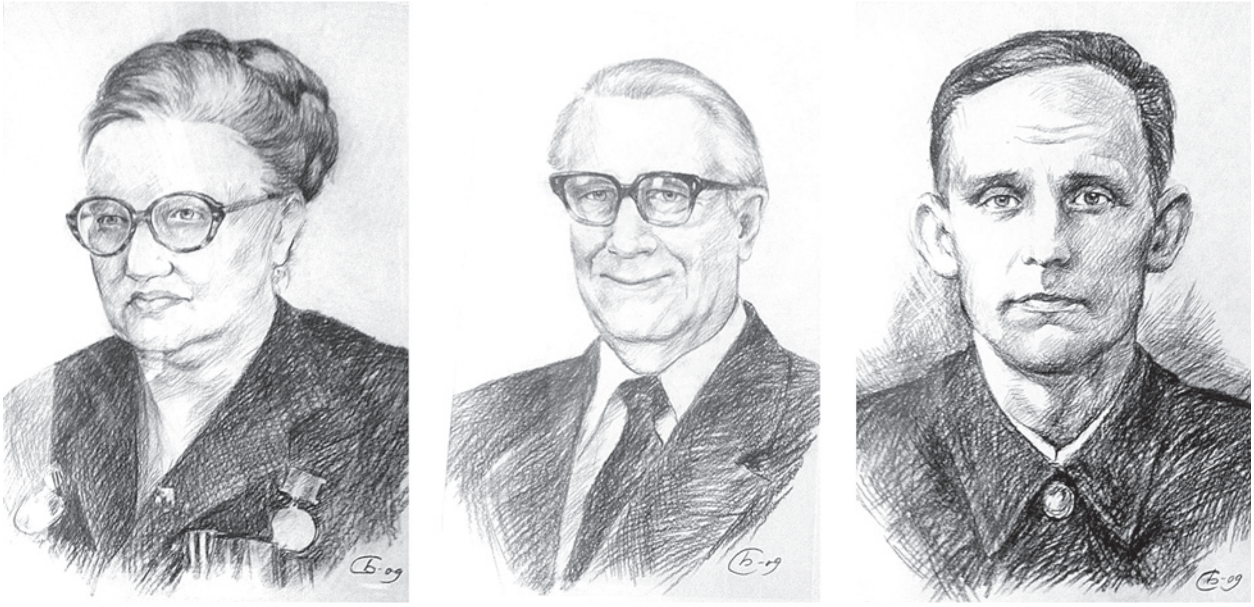
## EARLY DAYS OF THE SAFETY ENGINEERING DEPARTMENT

In the early 1950, Pyotr N. Bolkhovitinov, Candidate of Technical Sciences and Associate Professor, became the head of the Department. The name of the Department was changed to Safety Engineering[4, 5].

In 1953–1966, the Department was headed by Lidiya A. Khokhlova (Neustroyeva), Candidate of Technical Sciences and Associate Professor (*Fig. 1*).

Major organizational and methodological work was carried out under her leadership[6, 7, 8] to put together lecture courses, improve training aids and facilities, recruit and train skilled teaching and research personnel. In

[1] An associate professorship was a transitional entity between instructors in Safety Engineering and Fire Safety Equipment scattered across different departments and a single entity, a department.
[2] Order No. 11/k dated January 29, 1949 for the Leningrad Order of Lenin Institute of Railway Engineers.
[3] Order No. 63/k dated July 04, 1949 for the Leningrad Order of Lenin Institute of Railway Engineers.
[4] Order No. 5/al dated January 03, 1950 "On teaching" for the Leningrad Order of Lenin Institute of Railway Engineers.
[5] Order No. 408/al dated December 20, 1952 "On teaching" for the Leningrad Order of Lenin Institute of Railway Engineers.
[6] Order of the Leningrad Order of Lenin Institute of Railway Engineers named after Academician V.N. Obraztsov No. 10/al dated January 15, 1953 "On teaching".
[7] Order of the Leningrad Order of Lenin Institute of Railway Engineers named after Academician V.N. Obraztsov No. 379/al dated December 22, 1955 "On teaching".
[8] Order of the Leningrad Order of Lenin Institute of Railway Engineers named after Academician V.N. Obraztsov No. 359/al dated February 23, 1956 "On teaching".



Lidiya A. Khokhlova Georgy E. Skorodumov Evgeny V. Bobin

**Fig. 1.** Department heads in 1953–1977

1960, a fundamental research laboratory for industrial noise control in railway transport was established[9]. The main focus of the laboratory was research to identify equipment and technological processes with noise levels exceeding sanitary standards and providing assistance to transport enterprises in developing new low-noise designs for machinery and mechanisms. Engineer Evgeny V. Bobin was appointed the head of the laboratory.

In 1964, the Department established a research laboratory for transport aesthetics headed by engineer E.S. Kadukov in accordance with the plan for comprehensive scientific experimental research in engineering aesthetics for the improvement of working conditions and productivity which was developed in cooperation with October Railways[10].

Order No. 175/k dated December 03, 1965 changed the Department's name to Occupational Health and Safety and the course Fundamentals of Safety and Fire Safety was renamed Occupational Health and Safety[11].

In 1966–1976, the Department was headed by Georgy E. Skorodumov, Candidate of Technical Sciences[12, 13].

Under his leadership, the educational laboratories were modernized, a specialized educational laboratory for occupational health and safety was established, and the Department's scientific base was substantially enhanced. In 1967, a monograph *Noise and Vibration Control in Railway Transport* by Evgeny V. Bobin was published [1]. The same year, the first textbook for university students, *Occupational Health and Safety in Railway Transport*, was published with the contribution of Department members, first of all Associate Professor V.V. Granqvist [2].

In 1976–1977, the Department was headed by Candidate of Technical Sciences Evgeny V. Bobin[13, 14].

## DEVELOPMENT OF THE OCCUPATIONAL HEALTH, SAFETY AND ENVIRONMENTAL PROTECTION DEPARTMENT

In 1977–1992, the Department rapidly developed under the guidance of Nikolai N. Maslov, Doctor of

[9] Order of the Leningrad Order of Lenin Institute of Railway Engineers named after Academician V.N. Obraztsov No. 174/k dated November 23, 1960.
[10] Order of the Leningrad Order of Lenin Institute of Railway Engineers named after Academician V.N. Obraztsov No. 212/k dated December 30, 1964.
[11] Order of the Leningrad Order of Lenin Institute of Railway Engineers named after Academician V.N. Obraztsov No. 175/k dated December 03, 1965.
[12] Order of the Leningrad Order of Lenin Institute of Railway Engineers named after Academician V.N. Obraztsov No. 267/al dated June 16, 1966.
[13] Order of the Leningrad Order of Lenin Institute of Railway Engineers named after Academician V.N. Obraztsov No. 131/al dated March 22, 1976.
[14] Order of the Leningrad Order of Lenin Institute of Railway Engineers named after Academician V.N. Obraztsov No. 466/al dated October 17, 1977.

**Fig. 2.** Nikolai N. Maslov

Technical Sciences, Professor, and Honoured Inventor of the USSR[14, 15] (*Fig. 2*).

Under his leadership, the Department expanded the scope of its research interests. The list of research areas of the Department included environmental protection, resulting in changing its name to Occupational Health, Safety and Environmental Protection.

During this period, the Department's educational laboratory was provided with new technical teaching aids, rooms for business simulation games on occupational health, safety and environmental protection were set up, and publishing activities picked up momentum. The Department maintained contacts with 150 organizations across the country, such as higher education institutions, research and design institutes, design bureaus, and factories. The Department's teachers and researchers (*Fig. 3*) collaborated with all railway universities in the Soviet Union. As part of their R&D activities, they worked with enterprises from Murmansk to Vladivostok, and almost with all of the Soviet Union Republics, in particular, the Baltic Republics and Ukraine. For example, they worked with the Darnytsky Wagon Factory, the Ukrainian Soviet Socialist Republic, on issues related to industrial aesthetics and workplace ergonomics, analyzing and evaluating working conditions, and developing measures to improve them. A machine for cleaning diesel locomotive units and parts during major repairs developed by the Department was introduced at the Daugavpils Locomotive Repair Plant in the Latvian Soviet Socialist Republic. The tunnel dust control processes designed by the

**Fig. 3.** Team of the Occupational Health, Safety and Environmental Protection Department in the 1970s

[15] Order of the Leningrad Order of Lenin Institute of Railway Engineers named after Academician V.N. Obraztsov No. 88/al dated February 22, 1978.

**Fig. 4.** President of Russian Railways OJSC Vladimir Yakunin hands out an industry award to Gennady K. Zaltsman (right)

Department were introduced in metro systems of the Soviet Union.

A monograph by the head of the Department's Industry Research Laboratory, Candidate of Technical Sciences N.I. Ivanov *Noise Control on Track and Construction Machinery* was published in 1979 [3]. A monograph by Candidate of Technical Sciences N.A. Bobrovnikov *Environmental Protection from Dust in Transport* was published in 1984 [4]. A book by Professor Nikolai N. Maslov and Professor Viktor A. Elsukov *Occupational Health and Safety in Metro Systems* was published in 1985 [5]. The first textbook for students of railway universities, *Environmental Protection in Railway Transport*, written by Professor Nikolai N. Maslov in collaboration with Yu.I. Korobov came out [6].

In 1993–2006, the Department was headed by Professor Gennady K. Zaltsman[16] (*Fig. 4*).

In 1995, a unified research laboratory was established under his leadership, bringing together all occupational health and safety research efforts of the Department. A number of research works were commissioned directly by Russia's Ministry of Railways. 1996 saw the establishment of an expert information centre for collective and personal protective equipment for railway workers. Since 2002, the Department has been training students in Safety of Technological Processes and Operations.

In January 2004, as the Department launched a new specialty and the University established the Engineering Ecology Department, the Department's name was changed from Occupational Health, Safety and Environmental Protection to Occupational Health and Industrial Safety[17].

## A NEW STAGE IN THE WORK OF THE DEPARTMENT OF OCCUPATIONAL HEALTH AND INDUSTRIAL SAFETY – TECHNOSPHERE AND ENVIRONMENTAL SAFETY

Since 2006, the Department has been headed by Tamila S. Titova, Doctor of Technical Sciences, Professor, and Honoured Science Worker of the Russian Federation (*Fig. 5*).

**Fig. 5.** Tamila S. Titova

In November 2006, a decision of the Academic Board renamed the Department to Technosphere and Environmental Safety[18], giving impetus to a large-scale process of renaming departments that train safety professionals in higher education institutions across Russia.

On November 21–23, 2007, the Department organized and held the I International Science-to-Practice Conference "Technosphere and Environmental Safety in Transport". The plenary session and roundtables that took place in the Constantine Palace in Strelna attracted the attention of not only professors of transport universities that train HSE specialists, but also representatives of executive authorities and supervisory agencies for labour and rail transport. The relevance of the issues raised at the Conference and the interest of its participants in discussing them showed the need for

[16] Order of St. Petersburg State Transport University No. 768/ok dated March 23, 1993 "On teaching staff".
[17] Order of St. Petersburg State Transport University of the Ministry of Railways of the Russian Federation No. 3/dd dated January 16, 2004 "On renaming the Occupational Health, Safety and Environmental Protection Department".
[18] Order of St. Petersburg State Transport University (GOU VPO PGUPS) No. 18/od dated November 30, 2006 "On renaming the Occupational Health and Industrial Safety Department".


**Fig. 6.** Department team (2008)

regular meetings in this format. Since 2008, the Conference has been held every two years and thus become a customary event. The second conference, which has been since then known as "TABTRANS", revealed the essence of the concept of "technosphere safety" and it was subsequently taken into account when new health and safety training standards were developed. Thus, the Department is one of the early pioneers in a new area of human life and health protection, which in 2009 was shaped as a separate scientific discipline with an approved professional training programme, bringing together all possible areas of training in occupational safety.

In November 2008, the Department team increased through a merger with the Ecology Department[19] (*Fig. 6*), and its scope of work expanded, too. The research laboratories were transformed into a testing centre for Environmental Safety and Occupational Health and Safety.

In 2011, the Ministry of Education and Science of Russia changed the list of specialties and fields of study for admission and training of higher education students. At that point, the Department had to discontinue admission and training of specialist students and launched a bachelor degree programme in Technosphere Safety, specialty 20.03.01 (with the major in Safety of Technological Processes and Operations) and a master degree programme in Technosphere Safety, specialty 20.04.01 (Hazardous Technological Processes and Operations).

## PUBLISHING ACTIVITIES OF DEPARTMENT MEMBERS

Among a large number of textbooks, teaching guides, and research papers prepared by employees of the Department, worth mentioning are thr publications widely used for training both by the Technosphere and Environmental Safety Department at PGUPS and by many other departments of Russian universities training safety engineers. These are the study guide *Industrial Safety* prepared by the Department's team and published in 2010 under the editorship of Tamila

[19] Order of St. Petersburg State Transport University (GOU VPO PGUPS) No. 6/od dated November 28, 2008 "On reorganizing the Engineering Ecology Department and the Technosphere and Environmental Safety Department".


**Fig. 7.** Study guide Occupational Health and Safety in Rail Transport

S. Titova (reprinted in 2016) [7, 8], and the study guide *Occupational Health and Safety in Rail Transport* published in 2017 [9] (*Fig. 7*).

## DEPARTMENT NOWADAYS

The skills of the graduates in the master degree programme, the high reputation of the Department among employers, and multiple requests from prospective students and employers enabled the first admission of students to the master degree programme in Environmental Engineering in 2022.

The hallmark of the Department is that it contributes to training of each and every student of the University. The Health and Safety discipline is in the curricula of all specialties and areas of training. Moreover, its content substantially varies for mechanics, builders, traffic engineers, and economists. Besides, the Ecology course is available for many specialties. Every year, the Department trains about 4,000 students of all modes of attendance.

**Fig. 8.** Department team (2014)

**Fig. 9.** Department team (2024)

By the celebration of its 75th anniversary, the Department boasts a close-knit team which includes three professors (Doctors of Sciences), nine associate professors (Candidates of Sciences), two senior lecturers, and one assistant (*Fig. 8*, *9*).

## CONCLUSION

2007 saw the first graduation of specialists in Occupational Health and Safety. Since then, the Department has trained over 350 specialists and bachelors and more than 50 masters for industry, transport and other sectors. Graduates from the Department are successful on the labour market. You can meet them anywhere in Russia, from Kaliningrad to the Far East. The majority of them are employed by railway member companies of Russian Railways OJSC, Gazprom, the St. Petersburg Metro, Severstal Steel Mill in Cherepovets, and other companies in Russia. Many graduates work in supervisory agencies and expert organizations.

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# Development of passenger transportation on Indian railways: The end of the 20th and the first decades of the 21st century

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ABSTRACT At the end of the 20th century and in the first decades of the 21st century, India achieved significant success in modernizing its rail transport. Good progress has been achieved in almost all branches of the railway sector. The infrastructure has been improved — the Project Unigauge, a nationwide initiative aimed at converting the country's railway network into a single wide (1,676 mm) gauge system, has been almost completed. Currently, broad gauge railways account for about 97% of the total operational length. In parallel with the reconstruction of the tracks, many bridge crossings have been renovated, and improvement of station and logistics facilities is underway. The electrification of broad gauge tracks is nearing completion; electrified lines currently account for more than 99% of their total length. Railway automation, telecontrol and telecommunication systems are being intensively modernized, and digital technologies are being increasingly used. The rolling stock is being radically updated, including both traction facilities and passenger and freight carriage fleets. High-speed traffic is developing, and the construction of India's first specialized Mumbai–Ahmedabad high-speed rail line is being completed. The article examines one of the activities of the railways of India — long-distance railway passenger transportation. The authors continue their historical research of the period from the appearance of the first railways in India in the 19th century to the present day. The previous parts of the study were published in this journal in 2023–2024[1].

KEYWORDS: Indian railways, passenger transportation, passenger rolling stock, EMU, passenger travel classes, travel comfort, ticket booking

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*Обзорная статья*

# Развитие пассажирских перевозок на железных дорогах Индии: конец XX столетия — первые десятилетия XXI века

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АННОТАЦИЯ В конце XX в. — в первые десятилетия XXI в. Индия добилась значительных успехов в модернизации железнодорожного транспорта. Положительные результаты были достигнуты практически во всех отраслях железнодорожного комплекса. Совершенствовалась инфраструктура — практически завершен общенациональный проект Unigauge, направленный на объединение железнодорожной сети страны в единую рельсовую систему с переустройством ее на широкую колею 1676 мм. В настоящее время железные дороги широкой колеи составляют около 97% всей эксплуатационной длины. Параллельно с реконструкцией путей обновлены многие мостовые переходы, совершенствуется станционное и логистическое хозяйство. Близок к завершению процесс электрификации магистралей широкой колеи, сегодня электрифицированные линии превышают 99% общей их протяженности. Интенсивно ведется модернизация систем железнодорожной автоматики, телемеханики и связи, все шире используются цифровые технологии. Кардинально обновляется подвижной состав: как средства тяги, так и пассажирский, грузовой вагонный парк. Развивается скоростное движение, завершается сооружение первой в Индии специализированной высокоскоростной железнодорожной магистрали Мумбаи – Ахмадабад.

В статье рассматривается одно из направлений деятельности железных дорог Индии — дальние пассажирские перевозки. Авторы продолжают историческое исследование периода от появления первых железных дорог в Индии в XIX в. до наших дней. Предыдущие части опубликованы в настоящем журнале в 2023–2024 гг.[2].

КЛЮЧЕВЫЕ СЛОВА: железные дороги Индии; пассажирские перевозки, подвижной состав; электропоезда; электросекции; EMU; классы проезда пассажиров, комфорт проезда; бронирование билетов

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## PHENOMENON OF DEVELOPING A NEED FOR MASS PASSENGER TRANSPORTATION IN INDIA

By 2024, the population of India exceeded 1.46 billion people[3]. Despite the fact that residents of India are less mobile than in many other countries, the number of passengers on rail transport, as the most accessible mode of transport for the majority of the population, is high, and in absolute terms, the number of passengers carried is higher than in China. For instance, in 2023, Indian railways (excluding metro systems) carried 6,396.0 million passengers as compared to 2,798.7 million passengers in China, despite the fact that the population numbers of the two countries are close. However, in China, rail travels cover on average longer distances, hence higher annual passenger figures: 1,341,037 million passenger-kilometers (2023) in China compared to 958,919 million passenger-kilometers in India. Nevertheless, this figure is also high in India[4].

High passenger traffic in India is largely contributed to by a significant number of the country's holidays, primarily religious ones. While India is a secular state, various studies show that less than 1% of its population consider themselves non-religious. The main religions practiced are Hinduism (about 80% of the population), Islam (about 14%), Christianity (2.5–3%), Sikhism (about 2%), and Buddhism (about 1%)[5].

In India, adherents of all religions have their own holidays. The country has 18 non-working public holidays during a year. For comparison, South Korea has

[2] *Захаров В.Б., Комаров Е.* Железные дороги Индии. Завершается важный этап модернизации — унификация ширины колеи. Транспорт БРИКС. 2023. Т. 2. Вып. 2. Ст. 1. https://doi.org/10.46684/2023.2.1.
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[3] Current World Population. URL: https://www.worldometers.info/world-population/.
[4] Statistics — Synopsis. 2025 UIC Publication 2024. URL: https://uic.org/IMG/pdf/railway_statistics_synopsis_2024web_1866037339.pdf
[5] BRICS. Trade Union Forum. URL: https://tufbrics.org/ru/info/28/.

17, Japan has 15, and Russia has 14 public holidays. In developed Christian countries, the average number of public holidays ranges between 11 and 13 (11 in the United States, 12 in Italy, and 13 in Germany)[6].

In 2025, India declared 78 religious holidays, mass public ceremonies, and remarkable dates of varying significance, from national holidays to events in individual states, groups of states, and municipalities[7].

In India, it is usual to celebrate holidays both of one's own faith and of other faiths with friends, acquaintances, co-workers, and neighbours. Because of this, the country's legislation limits the number of non-working days allotted to employees. Most of them have the right to choose 2 out of the 24 restricted holidays based on their nationality or religion.

Many Indians have a deeply ingrained traditional notion that during holidays they must visit their family members, friends, and, with the rise of prosperity in recent decades, often distant relatives — not just by degree of kinship but also literally "distant", those living far away. What seemed impossible just half a century ago — visiting relatives on holidays — is increasingly becoming the norm today, filling trains, buses, and planes on pre-holiday days.

In addition to religious holidays, there are secular ones, as well as numerous festivals, fairs, exhibitions, and popular sports competitions often held in the country. For example, the calendar of the main national fairs, exhibitions and festivals (excluding sports events) for January–December 2025 includes 51 events[8].

## RAILWAYS AS INDIA'S MAIN MODE OF TRANSPORT FOR MASS, LONG-DISTANCE PASSENGER TRANSPORTATION. IMPROVING THE PASSENGER RAIL ROLLING STOCK FLEET

Previous publications by the authors provide an overview of the main stages in the development of the passenger rolling stock fleet, from the inception of the Indian railways in the 19th century to the mid-20th century[1, 2]. A major achievement of the Indian railways after the country's independence in 1947 was the creation of its own coach-building industry.

In 1955, Integral Coach Factory (ICF), one of the first major mechanical engineering companies in


**Fig. 1.** ICF coach with Second Class seats on the Mumbai (CSMT)–Pune Pragati Express (12125). Photo by the authors. March 2019

the independent India, was established in Chennai (known as Madras before 1996), with technical assistance from Swiss Car and Elevator Manufacturing Corporation Ltd.

Indian engineers in cooperation with Schweizerische Wagons- und Aufzügefabrik AG (SWS, Swiss Railcar and Lift Factory Corporation, known colloquially as "Wagi", which was based at Schlieren, canton of Zurich, Switzerland) designed a new 22.2 m long (over buffers), 3.2 m wide, and 4.0 m high 1,676 mm gauge unibody coach that could travel at a maximum speed of 130 km/h. It is important to note that by the mid-20th century, a significant portion of the rail coach fleet of the Indian railways still had either a wooden body frame or a wooden body on a steel frame [1].

Release of new rail coaches fully meeting the requirements of the 1950s started on October 2, 1955. The ceremony was attended by India's Prime Minister Jawaharlal Nehru.

Starting with 350 coaches per year, the Integral Coach Factory now manufactures 1,800 coaches per year of different types and various comfort level (class), air-conditioned and non-air-conditioned coaches, trailer and motor carriages (*Fig. 1*).

For more than 30 years, ICF coaches were the backbone of India's rail coach fleet. However, by the late 1980s, the overall obsolescence of coaches built in the late 1940s became increasingly evident.

The management and engineers of Indian Railways embarked on a search for structural concepts to create a new 1,676 mm gauge lightweight coach capable of traveling at a greater maximum speed of at least

[6] Public holidays in various countries. 2023. URL: https://www.snegovik.ru/articles-new-year/skolko-otdykhayut-v-raznykh-stranakh/.

[7] Holidays and Observances in India in 2025. URL: Holidays and Observances in India in 2025.

[8] Calendar of Events in India for 2025. Embassy of India Economic and Commerce Wing. Manila. URL: https://www.eoimanila.gov.in/docs/1733396115CALENDAR_OF_EVENTS_IN_INDIA2025-2026.pdf.

160 km/h. Besides, the coach was supposed to be safer in operation than ICF coaches, and in particular to prevent telescoping of the vehicle bodies in train collision accidents[9].

In 1995, Linke-Hofmann-Busch (LHB) was chosen as a contractor. Later it changed its owner and became Alstom LHB GmbH in 1998. The company was awarded two contracts: to design a new high-speed coach for the 1,676 mm gauge and to transfer technology and launch manufacturing of coaches at an Indian facility[10].

In 1998, the first LHB high-speed rail coaches were manufactured. During test runs, they reached a speed of 180 km/h (the maximum speed in commercial service is 160 km/h). In 2000, large-scale manufacturing of various types of rail coaches began, including service carriages with electric generators and luggage compartments (*Fig. 2*, *3*).

**Fig. 2.** LHB coach with air conditioning and three-tier sleeping berths (3AC) (with reserved seats). Photo by the authors. March 2019

**Fig. 3.** LHB carriage with an electric generator and luggage compartment. Photo by the authors. March 2019

At present, coach-building factories in India manufacture a wide range of passenger rail coaches. The rolling stock will soon be supplemented with vehicles manufactured by Kinet Railway Solutions, a Russian-Indian joint venture, which will launch the production of the Vande Bharat[11] — modern, high-speed AC multiple-unit trains for the 1,676 mm gauge. The train is a proprietary Indian solution of the Integral Coach Factory in Chennai as part of the Make in India initiative launched by the Indian Government (*Fig. 4*). The prototype was created in 2018 and reached a speed of 183 km/h during test runs. (Its design speed is 160 km/h.) The train is made up of 8, 16 or 20 coaches of various classes and is designed for operation on routes of up to 800 km.

**Fig. 4.** One of the first Vande Bharat trains[12]

The first Vande Bharat Express was put into operation in February 2019. In January 2025, 66 trains were in operation providing services on more than 150 routes, including 15 trains of 16 coaches, 8 trains of 20 coaches, and 43 trains of 8 coaches [2, 3].

Vande Bharat trains are manufactured at several coach-building factories in India and have proven themselves as reliable, economical, and comfortable vehicles for passengers. A decision was made to buy several thousands of these trains in the coming years [4]. In 2022, the Government of India announced an international tender for setting up manufacturing of the latest modification of the Vande Bharat in India.

In 2023, a consortium led by Transmashholding JSC, Russia, won a USD6.5 billion international tender for the design, manufacturing and 35-year maintenance of 1,920 coaches for long-haul Vande Bharat electric trains in three passenger classes. Kinet Railway Solutions, a Russian-Indian joint venture, was established for this purpose [2]. The prototype of the first Vande Bharat from Kinet Railway Solutions is ex-

[9] Telescoping occurs when the underframe of one carriage smashes through the other carriage's body as a result of a catastrophic collision. The resulting appearance of the two vehicles resembles the tubes (segments) of a telescope (spyglass) inserted into each other.

[10] Linke-Hofmann-Busch (LHB). URL: https://transportpedia.org/manufacturers/lhb.

[11] Initially, this was known as "Train 18". In 2018, the name was changed to "Vande Bharat" (meaning "I glorify India" or "I bow to India" in Hindi).

[12] Make in India: creating a new center for railway engineering Rolling Stock. TMX Август, 2023. URL: https://rollingstockworld.ru/proizvodstvo/make-in-india-sozdavaya-novyj-czentr-zheleznodorozhnogo-mashinostroeniya/

**Fig. 5.** Exterior of the new Vande Bharat train designed by Kinet Railway Solutions. Design presentation[13]

**Fig. 6.** Interior of a sleeper compartment on the new Vande Bharat train designed by Kinet Railway Solutions. Design presentation[13]

**Fig. 7.** Interior of a Vande Bharat sleeper coach designed by Kinet Railway Solutions. The coach has an open-plan layout with two-tiers of berths for passengers (similar to a Russian-style "reserved seat" coach). Design presentation[13]

pected to be released in 2026 [4]. In March 2024, the company published a computer-aided design visualisation of the exterior and interiors of the new train coaches (*Fig. 5–7*).

## CURRENT STRUCTURE OF PASSENGER COACHES ON INDIAN RAILWAYS BY TRAVEL CONDITIONS AND COMFORT LEVEL

In India, railways remain the cheapest and most affordable mode of transport. Passengers riding on roofs of trains and literally hanging on to the outer structures of carriages, once typical of the country's railways, have almost become a thing of the past or can be seen on very rare occasions. Nevertheless, it is quite difficult to buy a ticket for many railway lines on the eve of public holidays, religious or public activities, trains are overcrowded, often exceeding the standard capacity, especially in cheaper classes. Indian Railways has to organise and introduce additional "holiday trains" in pre-holiday periods. Organise and introduce are not reserved and passengers occupy the entire space of the coach. The launch of these trains is widely announced before major holidays [5].

India has 11 classes of passenger trains and coaches, varying by the travel comfort level, seating type, availability of basic and additional services, and fare [6–9].

There are two main groups of coach classes, primarily depending on whether air conditioning is available or not. Given the climatic conditions in most regions of India, it is air conditioning in passenger rail coaches that determines the level of travel comfort during significant periods of the year.

In travel documents, coaches with air conditioning are designated as "AC" (air-conditioned). To designate an air-conditioned coach, the "A.C." letters are usually written on its side wall.

### AC (Air-conditioned) Classes

#### 1AC or 1A. *AC First Class: air-conditioned sleepers*

Passengers are accommodated on berths in two- and four-berth compartments with lockable doors (*Fig. 8*). At the ends of the corridor, each coach has two toilets, an Asian-style toilet[14] and a Western/European-style toilet. The latest series of coaches are provided with environmentally friendly, vacuum evacuation toilets, which passengers can use at any time, including the dwell time at a station

Each berth is provided with a full bedding set and a pillow. For all air-conditioned classes, bedding is included in the ticket price. First Class is the most expensive among sleepers.

[13] The public was shown the design of Russian trains for intended for Indian Railways. March 2024. URL: https://salt.news/promishlennost/publike-prezentovan-dizajn-rossijskih-poezdov-dlya-indijskih-zheleznyh-dorog
[14] The so-called Asian or squat toilets are common in some Asian and African countries. In many Muslim countries, washing with water is a mandatory cultural practice and it is easier done in this type of toilet than in a sitting position in European toilets.

*a*

*b*

**Fig. 8.** AC1 LHB coach: *a* — exterior on the Rajdhani Express (Mumbai–Delhi Rajdhani); *b* — AC1 two-berth sleeper on the Rajdhani Express. This is a two-berth compartment on the Mumbai–Delhi Rajdhani Express. *Photos courtesy of Nonstop Eurotrip [8]*

**2AC or 2A.** ***Two-Tier Class:*** Two-tier berths with air conditioning. There are compartments without doors (thick fabric curtains are available) along the side aisle, each has four berths across the coach and two side berths. Each berth is provided with a pillow, sheet, blanket, and face towel. There are two toilets at each end of the coach (in total, four): an Asian toilet and a Western one. In these carriages, washbasins are installed in the entrance vestibules. The price for the air-conditioned two-tier class is almost half the cost of the AC First Class (*Fig. 9*).

**Fig. 9.** Interior of a bay on a 2AC coach. View from the four transverse sleeping berths to the two longitudinal berths, with the lower berths converted to seats during the daytime. *Photos courtesy of Nonstop Eurotrip [8]*

**3AC or 3A.** ***AC Three-Tier: Air-conditioned coaches with berths arranged in three tiers in transverse bays and two tiers in side longitudinal bays.*** These coaches also have bays without doors (and without curtains) as in two-tier coaches, but the transverse rows have three berths one above the other, at the lower, middle, and upper tier. During the daytime, the middle berth is folded down, allowing three passengers to sit on the lower berth. The side berths are arranged in two tiers only (no middle berth is available). Each berth is provided with a pillow, sheet, and blanket.

**3E** ***AC Three-Tier-economy. Air-conditioned coaches with all berths arranged in three tiers, including in side bays.*** What differs it from 3AC is that side longitudinal bays have one more berth. This class is the cheapest among air-conditioned sleepers.

**EA.** ***Executive Anubhuti Chair Car:*** **Air-Conditioned Executive Class with comfortable, soft collapsible seats — the so-called Anubhuti coaches (in Hindi Anubhuti means feelings, sensations).** Relatively wide seats are arranged in rows in a 2+2 configuration across the coach and spaced relatively far apart, providing passengers with some degree of privacy (*Fig. 10*). Recently, branded express trains have been

**Fig. 10.** Interior of Executive Anubhuti Chair Car (EA) on the Shatabdi Express[15]

[15] Anubhuti AC chair for Shatabdi. The Hindu. December 2017. URL: https://www.thehindu.com/news/cities/Hyderabad/anubhuti-ac-chair-for-shatabdi/article22277934.ece

**Fig. 11.** Interior of CC coach of the Vande-Bharat train. Photos courtesy of Nonstop Eurotrip [8]

provided with mechanised seats with remote controls, so that passengers can convert them into a berth-like sleeping space, similar to business class on airplanes. Additional amenities include TV sets mounted on the front seatbacks. This class is quite popular with wealthy people traveling on daytime trains with a travel time of up to five hours. These executive class coaches are included in several comfortable express trains, such as the Tejas Express, Gatimaan Express, and Shatabdi Express. The ticket price is close to that for domestic air flights.

**EC.** ***Executive Chair Class: Air-conditioned coaches with comfortable collapsible seats*** (Air-Conditioned Executive Chair Class). Chairs are arranged in a 2+2 configuration across the carriage and have no additional equipment that is available on EA coaches.

**CC.** ***AC Chair Car: Air-conditioned coaches with soft chairs*** arranged in transverse rows in a 2+3 configuration (*Fig. 11*). The chairs are narrower than those in the Executive Chair Class and are closer to each other. This class of coaches is most frequently found in daytime trains with travel times of up to five hours.

## Non-Air-Conditioned Classes

**F or FC.** ***First Class without air conditioning.*** In this class, coaches are arranged in the configuration similar to that of air-conditioned first class coaches. Bedding is available for an extra fee. In recent years, this class of coaches is gradually put out of service (*Fig. 12*), and passengers are increasingly giving preference to 1C or 2C coaches.

**SL.** ***Sleeper Class.*** Coaches are arranged exactly in the same configuration as those with three tiers of berths, but have no air conditioning. Bedding is not included in the ticket price, but is available for an extra fee. Passengers are increasingly opting for 2AC coaches over these ones.

**2S.** ***Second Class.*** In India, this class provides an opportunity to travel by rail on reserved seats at the lowest price. The majority of second class coaches (*Fig. 13–17*) have wooden benches placed installed

**Fig. 12.** Non-air-conditioned first class (F or FC) ICF coach. Photo by the authors, 2019

*a* *b*

**Fig. 13.** Non-air-conditioned second class (2S) ICF coach: *a* — exterior of a train at the platform before boarding (the luggage ready for loading); *b* — interior of a coach with benches, each for three passengers. Photo by the authors, 2013

**Fig. 14.** Non-air-conditioned 2S ICF coach. Asian/squat toilet. Photo by the authors. 2019

**Fig. 15.** Non-air-conditioned 2S ICF coach. European/western toilet. Photo by the authors. 2019

**Fig. 16.** Non-air-conditioned 2S ICF coach. Entrance vestibule. Washbasin. Photo by the authors. 2019

across the central aisle of the carriage. Each bench can accommodate three passengers. Most second class coaches have no window glass, but are equipped with grilles to prevent unauthorized persons from getting into the carriage from platforms and protect passengers from accidental falling out. As windows have no glazing, but there are thick pull-down curtains (these can be seen in *Fig. 13*, *a*), passengers can ventilate the cabin.

**GN. *Unreserved/General Class.*** The class name "GN" stands for General Number (*Fig. 18*). It uses both seating coaches and coaches with two- or three-tier berths (similarly to SL coaches). This is the cheapest class. Similarly to non-air-conditioned second class, the majority of these coaches have no window glazing, but there are fixed grills and thick drop-down curtains.

To conclude this overview of the structure of passenger train classes of Indian Railways, let us compare approximate fares on the example of a trip by the


**Fig. 17.** Non-air-conditioned 2S ICF coach. Entrance vestibule. Folding berth for an on-duty attendant. Photo by the authors. 2019

**Fig. 18.** Non-air-conditioned ICF coach. GN: unreserved/general class with seating. Photo by the authors. 2019

New Delhi Rajdhani Express 2050 along the 1,072 km railway route between New Dehli and Samastipur where an approximate travel time is 18 hours 30 minutes. For reference, the travel time by air is 2 hours 57 minutes.

Indian Railways has fixed travel fares for different passenger coach categories. The AC First Class fare is approximately equivalent to the cost of a flight. For the route in question, a passenger will pay 3,500 rupees for AC First Class, 2,700 rupees for AC 2, and 1,455 rupees for AC 3 (as of 2022).

## MODERN RESERVATION AND TICKETING SYSTEM ON INDIAN RAILWAYS

Until the late 20th century, India had a generally archaic ticketing system, where tickets could be bought at railway stations. The system was limited to individual railway companies. Accounting for and registration of available tickets, distribution of seats for selling through specific ticket offices, and similar operations were done manually by railway operators with the use of telephone and telegraph [10].

Passengers had many complaints regarding the system. Booking errors, duplicate tickets sold, and misuses were frequent, for example, tickets for popular destinations were bought up and then resold at a higher price, etc.

In 1999, the Government of India founded, through its Ministry of Railways, the Indian Railway Catering and Tourism Corporation (IRCTC). It was designed to organize a system for booking and selling railway tickets, on-board catering, and tourist services [10].

On August 3, 2020, IRCTC launched an online ticketing system for Indian Railways. This digital innovation marked the switch from conventional ticket offices to online booking via an accessible platform. The launch of the IRCTC website was a revolutionary step in the development of ticket booking for millions of travellers [9].

In general, the system made the booking process more transparent for passengers. It also takes account of various factors when providing railway tickets to different groups of passengers, based on differences in their social status, gender, age, and so on. The system became more publicly perceived as a fairer one, given the existing shortage of carrying capacity in passenger traffic, especially on pre-holiday days.

In 2012, the Rolling Deposit Scheme (RDS) was introduced to simplify booking. It is a sort of a "wallet" that allows customers to book tickets using the deposited funds they deposit. In 2013, IRCTC expanded its services to include hotel and air travel booking.

When buying tickets for long-distance trains via the IRCTC system on the official website of Indian Railways (irctc.co.in), as well as through a ticket office at a railway station, one passenger can get no more than six tickets per train, which should be kept in mind when traveling as a large group. The IRCTC system does not guarantee that your seat and seats of your companions will be next to each other — it is a kind of lottery. When booking a ticket, you can state your preferences, such as "window", "aisle", "lower berth", "side berth", etc., but in reality, it is only upon boarding when the passenger learns where their seat is.

The exceptions are the air-conditioned Executive Chair Class (EC); air-conditioned First Class coaches with sleeping berths (1AC); AC Chair Class; and non-air-conditioned First Class (FC).

For all the other classes, when boarding the train, you must check whether your ticket is listed on the so-called charts, displayed on special information stands on platforms or outside of the coach. Charts may be displayed one or two hours before the train departure, but sometimes this happens just a few minutes before the departure (*Fig. 19–21*). An automatically generated seat number is indicated in charts. A seat is selected by computer based on the gender and age information for all the passengers traveling in the class.

Since usually there are not enough seats for everyone on any train, the e-ticketing system has special protocols for those who want to buy tickets: RAC (Reservation Against Cancellation) and WL (Waiting List).

The queue for tickets under the RAC protocol starts forming immediately after all of the reserved seats have been sold. After a while, no RAC seats are left and the system begins to generate a WL queue.

WL tickets indicate mean that all seats on the train have been sold out, but you can buy a place in the queue. When buying a place in the queue, a potential passenger is assigned a unique number which shows how many people are ahead of them on the waiting list. If someone cancels their ticket, the system automatically allocates it to the next person in the queue.

RAC tickets mean that passengers have purchased half a seat (for example one lower side seat). If someone cancels their ticket, the seats are first allocated to RAC members and then to WL members. If no one cancels a ticket, two RAC members are guaranteed one lower berth.

The booking and ticketing system of Indian Railways is constantly improved to benefit passengers and improve capacity utilization. Until the summer of 2025, the above mentioned chartrs (booking schemes) were prepared and displayed four hours before the departure, which created difficulties and uncertainty for passengers, especially those arriving at stations from regions. Currently, measures are being taken to ensure chartrs are prepared eight hours before the departure [11, 12].

The IRCTC system serves millions of people every day by booking and selling railway tickets, which is not easy, given the limited transport resources on railways, as well as personal needs, financial capabilities, timeframes, and limitations of each of millions

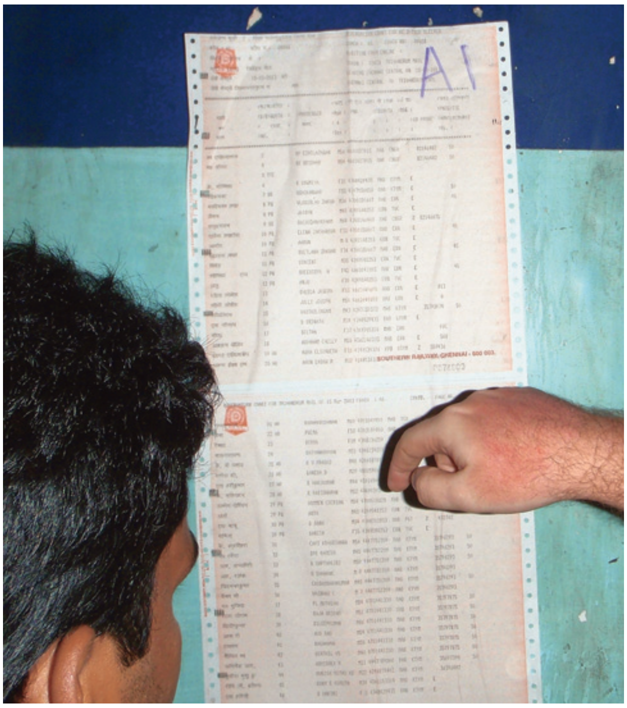

**Fig. 19.** Chart with names and surnames of passengers displayed on an information stand or on the outside of the coach before train departure. It replaces tickets and boarding passes for passengers who have purchased e-tickets and presented their ID. Photo by the authors. 2013

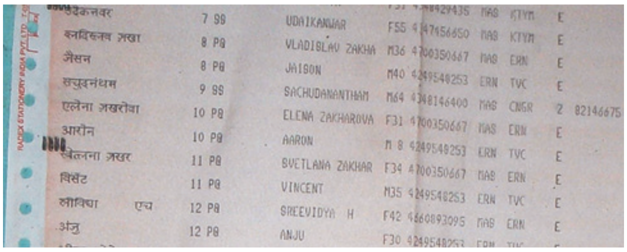


**Fig. 20.** The authors' names and surnames on a passenger chart. Photo by the authors. 2013

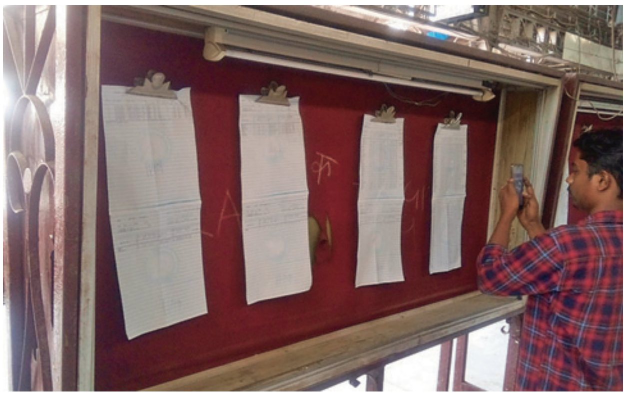

**Fig. 21.** Information stand on a passenger platform with charts listing names and surnames of passengers holding RAC and WL tickets. Photo by the authors. 2019

of people. In order to take into account all the priorities and satisfy the majority of interested passengers, the IRCTC system has introduced quotas for allocation of train seats among different categories of potential passengers[16].

Annually, quotas on the number of passengers in various transport (service) classes are set for 19 categories of passengers based on a review of the domestic passenger railway market in different classes/segments of transport. Some examples of quota categories include women; women over 45 years of age or women with children under 12 years of age traveling unaccompanied; people with disabilities; the military personnel; railway workers traveling for business; parliament members; foreign tourists, etc. The announced quota system for each line and each day helps manage the public perception of ticket shortage as an unpleasant but manageable situation[16].

## TOURIST AND LUXURY TRAINS ON INDIAN RAILWAYS

The story of long-distance passenger traffic on Indian railways would be incomplete without a brief description of increasingly popular highly comfortable trains known as luxury trains, as well as tourist trains attracting growing attention among both residents and foreign visitors [13].

Some luxury trains operate on routes overlapping with those of regular trains, but they differ from the latter in their refined luxury and comfort of coaches, including premium dining carriages. After all, the purposes of luxury trains, as well as regular ones, is to bring passengers from point A to point B, while providing them with a particularly comfortable, even luxurious, travel experience.

Tourist trains travel along special routes. What is important for travellers is not the fact that they travel to a certain destination, but the journey as such, where they have an opportunity to do sightseeing along the way, visiting beautiful natural sceneries or monuments of architecture and history.

Coaches of the majority of tourist trains have similar comfort classes as those above 2C and 3C found in modern Indian long-distance passenger trains, and they are ICF and LHB carriages.

At the same time, a number of tourist trains are distinguished by a high level of comfort and exquisite design of their carriages and hence can be referred to as luxury tourist trains. Designed to provide a very comfortable leisure experience, in terms of their functionality, they are close to river, sea or ocean cruise ships[17]. Luxury tourist trains are made up of highly comfortable coaches, but the design of some carriages also allows travellers to enjoy good views of the surroundings, as well as take photos and videos [13].

In some cases, tourist trains have an observation carriage (*Fig. 27–30*) at the rear of the train[18]. These carriages are used on the majority of world's railways as service ones for technical inspections of the track by managers and engineers of various levels. Due to increased train speeds, modern observation carriages have an enclosed rear area with wide panoramic windows on three sides.

On routes abundant in mountainous areas, tourist trains often have the so-called "dome cars", so that passengers can more easily get what can be notionally called "vertical views" or "vertical panoramas"[19]. These have a glazed roof or glazed sections on the top shaped as a glass dome or hump projecting several tens of centimetres above the roof (within the safe upper clearance of the train).

Apart from luxury tourist trains, relatively inexpensive tourist trains affordable to the general public that have a modest design, but are comfortable are increasingly operated by Indian Railways. In recent years, the rail coach-building industry in India has been manufacturing carriages for these trains that are close to standard ones in terms of comfort levels and technical equipment.

As a result of the Project Unigauge implemented by Indian Railways, broad-gauge rail lines currently account for about 97% of the total operational length of the country's railway network. Most metre- and

[16] IRCTC Quota List. URL: https://www.redbus.in/indian-railways/irctc-quota-list.

[17] Cruise ships are large passenger ships used mainly for vacationing. Unlike ocean liners, which are used for transport, cruise ships typically embark on round-trip voyages to various ports of call, where passengers may go on tours known as "shore excursions".

[18] Known since as early as the mid-19th century, these carriages originally had an open platform with railings at the rear of a vehicle. Passengers could safely go out onto it as the train moved. Being somewhat protected from the wind by the end wall of the carriage, passengers could enjoy a nearly 360-degree view of the surrounding terrain "running away" from the train. In the late 19th century, especially in the United States, observation cars were popular on luxury trains.

[19] A dome car is a type of passenger carriage that has a glass dome on the top of it, so that passengers sitting on the upper level of the carriage can have an all-round view of the surroundings or look upwards to capture vertical views of the mountains, which is impossible in regular passenger carriages.


**Fig. 22.** The Golden Chariot luxury tourist train [13]

narrow-gauge railways have been converted to broad-gauge or closed.

Some of metre- and narrow-gauge railways in India have been recognized as historical heritage and preserved. Their routes usually run through picturesque areas, making them extremely attractive to tourists. Regular routes of many broad-gauge railways also pass through picturesque natural areas. Thus, broad-, metre-, and narrow-gauge trains operate as tourist trains in India.

Luxury trains are made up of both older luxury saloon coaches that have undergone complete overhaul and renovation and new ones manufactured for the purpose on the basis of ICF and LHB passenger coaches. In recent decades, quite a few saloon coaches built in the first decades of the 20th century that are distinguished by sophisticated finishes, but technically too obsolete for regular operation have been taken out of service. Some of them have been thoroughly rebuilt including the restoration of the undercarriage, body, and braking equipment, and outfitted with modern air conditioners, sanitary facilities, and other devices. The interiors have been restored, too. These coaches have been put into operation as part of luxury trains and luxury tourist trains with the original corporate livery (*Fig. 22*).

At a rough estimate based on data available on the Internet and reference publications, there are more than fifty luxury trains, luxury tourist trains, and tourist trains in India.

On January 27, 1989, Indian Railways and Rajasthan Tourism Development Corporation (RTDC) put into service one of the first luxury tourist trains, the Palace on Wheels. It operates between Delhi and the state of Rajasthan[20], which is known for its royal culture and beautiful palaces. The train covers about 3,000 km, running through the cities of Jaipur, Jaisalmer, Jodhpur, Udaipur, and Ranthambore in eight days and bringing travellers to Agra to see one of the wonders of the world, the Taj Mahal (*Fig. 23*)[21] [13].

**Fig. 23.** Bedroom of a Presidential Suite on the Palace on Wheels luxury tourist train[21]

[20] Rajasthan is the largest state in India. Founded in 1949 in the historical region of Rajputana, it is located in the northwest of the country. Its capital and largest city is Jaipur.
[21] The Palace on Wheels. URL: www.thepalaceonwheels.org.

**Fig. 24.** Dining carriage on the Maharajas' Express luxury tourist train[23]

**Fig. 25.** Kitchen of the dining carriage on the Maharajas' Express[23]

We will use this train as an example to examine how luxury tourist trains are set up and arranged. The train has 20 carriages, 14 of which can accommodate 82 travellers. There are two classes of suite cabins: two Super Deluxe Presidential Suites and 39 Deluxe cabins.

In addition to 14 coaches with tourists, the train has a spa carriage offering a wide range of services to travellers, two dining carriages, and two service carriages for the train crew and service staff, which also have stockroom. The train has an electric power carriage, which supplies power for air conditioning, lighting in carriages, operation of eco-friendly evacuation toilets, etc. Other luxury tourist trains are set up approximately in the same way as the Palace on Wheels. The total number of carriages on various trains ranges from 14 to 23 (the Maharajas' Express)[22, 23].

The suites on the Palace on Wheels are named after precious stones. They are decorated using the colour of the corresponding stone and are lined with silk and velvet. The suite has a bedroom (*Fig. 23*), a study with a desk and sofa, and a private bathroom. Adjacent to the suite there is a service compartment for a butler [13].

Some of the interiors of passenger coaches on luxury tourist trains are shown below (*Fig. 24–26*).

Apart from luxury tourist trains, Indian Railways operate tourist trains for a broader range of travellers — people with middle income. For traveling on narrow-, metre-, and broad-gauge tracks, coach-making factories in India produce special tourist coaches known as "Vistadome" (from the English words *vista* (a distant view) and *dome*)[24] (*Fig. 27–30*).

Tourist routes also run along the metre- and narrow-gauge railways that still remain in service. In addition, a number of these lines are currently listed as Indian and UNESCO World Heritage Sites and taking a trip on them is of particular interest.

An earlier article published by the authors describes the rolling stock that was used for regular passenger traffic in the mid-20th century on metre- and

**Fig. 26.** Fitness centre on the Deccan-Odyssey luxury tourist train[25]

[22] The longest passenger train Prayagraj Express operates between New Delhi and Prayagraj and has 24 carriages.
[23] The Maharajas' Express. URL: https://www.tripadvisor.ru/Attraction_Review-g304551-d15133137-Reviews-Maharajas_Express-New_Delhi_National_Capital_Territory_of_Delhi.html
[24] The Vistadome. Enjoy expansive views of memorable routes. URL: https://artsandculture.google.com/story/the-vistadome-enjoy-expansive-views-of-memorable-routes-rail-enthusiasts-society/SwUhyI0V7j1BIA?hl=en.
[25] The Deccan Odyssey. URL: https://www.tripadvisor.com/Attraction_Review-g304554-d628517-Reviews-Deccan_Odyssey-Mumbai_Maharashtra.html#/media-atf/628517/354872336:p/?albumid=-160&type=0&category=-160.


**Fig. 27.** Vistadome (AC TOURIST CAR (LWTFCZAC/WTFCZAC). The glass roof and observation area at the rear of the coach are visible[24]

**Fig. 28.** Vistadome (AC TOURIST CAR (LWTFCZAC/WTFCZAC) with an observation area with wide glass windows at the rear of the coach[26]

**Fig. 29.** Vistadome (AC TOURIST CAR (LWTFCZAC/WTFCZAC). Interior of an observation area with wide glass windows at the rear of the coach[24]

narrow-gauge railways in India[27]. Later these carriages were also included in trains on tourist routes that opened on these lines.

In recent years, interest in tourist trips on historical railways, including metre- and narrow-gauge lines, has increased significantly. India's coach-making factories currently produce the second model of the Vistadome narrow-gauge carriage designed for tourist trains (*Fig. 31–34*).

The Him Darshan Express[28], a tourist train made up of 762 mm gauge Vistadome coaches, took its first trip on December 26, 2019 on the Kalka–Shimla Railway[29],

**Fig. 30.** Interior of the Vistadome (AC TOURIST CAR (LWTFCZAC/WTFCZAC) coach with tourists [14]

[26] The Vistadome Experience. URL: https://www.tripoto.com/karnataka/trips/the-vistadome-experience-3b4f69901a5636271.

[27] Zakharov V.B., Komarov E. Passenger Rolling Stock of Indian Railways in the First Half-Century of Their Operation. *BRICS Transport*. 2024;3(1):1-14. https://doi.org/10.46684/2024.1.2.
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[28] The name Him Darshan Express (The Himalayas Darshan Express) derives from a popular tourist viewpoint, the Himalaya Darshan, in the Himalayan foothills along the Kalka–Shimla railway.

[29] A 96.6 km long narrow-gauge mountain railway opened in 1903 connects Kalka (a city in Northern India, the state of Haryana) and Shimla (the capital of the state of Himachal Pradesh and a mountain resort in Northern India). The line made it possible to comfortably travel to the previously virtually inaccessible town of Shimla in the mountains in just six to seven hours. Small trains operated on this narrow-gauge line were called “toy trains” — a name still often used nowadays, especially by journalists.


**Fig. 31.** The first Kalka–Shimla Him Darshan Express with the first generation of Vistadome coaches with the glass roof. Departure from Kalka station. December 26, 2019 [15]

**Fig. 32.** Interior of the first-generation Vistadome coaches with the glass roof on the Kalka–Shimla Him Darshan Express [15]

**Fig. 33.** The Kalka–Shimla Him Darshan Express tourist train with the first-generation Vistadome coaches with the glass roof[30]

which is a UNESCO World Heritage Site [15]. The carriages looked much like old narrow-gauge ones, but had the glass roof for vertical views (*Fig. 31–33*). The train had one air-conditioned first-class coach.

In 2023, the Rail Coach Factory at Kapurthala[31] began to manufacture modern, comfortable 762 mm gauge Vistadome coaches with seats, panoramic windows, and a glass roof (*Fig. 34*, *35*). All carriages have air conditioning facilities [16].

## CONCLUSION

By the end of the first quarter of the 21st century, a significant progress has been made in the development of passenger travel on the Indian railways, which remain the primary mode of transport in the country with the largest population on the globe.

Passenger transport was improved through the implementation of the Project Unigauge, which has

[30] https://www.business-standard.com/article/current-affairs/trial-run-of-vistadome-coaches-on-kalka-shimla-route-to-be-conducted-soon-123010800177_1.html

[31] Founded in 1985, it is a coach-building factory of Indian Railways in the state of Penjab. Currently, it manufactures new LHB and MEMU passenger coaches and narrow-gauge railway carriages.

**Fig. 34.** A train comprised of new Vistadome coaches on the Kalka–Shimla Railway. A power carriage can be seen in the middle of the train [16]

**Fig. 35.** Interior of the new Vistadome coaches on the Kalka–Shimla Railway [16]

integrated the country's entire railway network into a 1,676 mm gauge system, accounting for about 97% of the total operational length of railways in India.

The near completion of the electrification of broad-gauge trunk lines, which currently account for about 99% of the total operational length, is also very important for enhancing the operation of the country's railways. This has made it possible to increase speeds, the weight of freight trains, and the length of passenger trains, and improved compliance with the timetable for passenger trains. The projects to build a single broad-gauge railway system and electrify the Indian railways were implemented in combination with the renewal of the rolling stock fleet, both freight and passenger carriages and traction units, using powerful electric locomotives and modern multiple unit passenger trains for both commuting and long-distance travels.

The electrification of railways has significantly improved the environmental situation, brought the country closer to zero carbon emissions, and substantially reduced its dependence on exports of liquid hydrocarbon fuels for diesel locomotives. In India's locomotive fleet, diesel locomotives are gradually converted into stand-by power units intended for use in emergency situations, in particular, in case of climate disasters (hurricanes, natural calamities), when disruptions to railway power supply are possible.

It should be noted that the country's transition to a single railway system with a broad gauge of 1,676 mm, which is not a standard gauge in the world, is likely to create difficulties in operating both the standard 1,435 mm (HSR) and broad gauge rail systems in passenger traffic in the future. This is predicted based on ambitious plans to build a high-speed rail (HSR) network, which, according to international experience, can be assumed to be built on a standard 1,435 mm gauge.

Nevertheless, we can currently see a significant progress in the comprehensive modernization of Indian railway transport, a dramatic improvement in passenger service, making it more accessible to people, and increasing travel speeds, comfort, and safety levels.

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