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Priorities of Scientific and Technological Development of the Railway Industry in the Context of Digitalization: International Expertise




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ABSTRACT

Digitalization opens new opportunities and ways of doing business in all sectors of the economy. This process does not bypass the railway industry. The criticality of digitalization of the industry is explained by the widespread use of railway transport, and the increasing demand on quality and speed of providing transportation services. The article is devoted to the analysis of the priorities of digital transformation of the railway industry and highlights key trends of digital transformation, as well as priority areas of scientific and technological developments. The objective is to describe a three-level study of prospects for scientific and technological development of the railway industry in the context of digitalization of the economy based on application of the methods of system analysis to international expertise and practices. The first level of the study was devoted to identification of the main directions of development of digital technologies which can be applied to railway transport; the second level was the analysis of strategic railway documents developed in some regions followed by identification of key trends in digital development; the third one made it possible to identify the most effective information technologies to be implemented for railways, particularly in the Russian Federation.

Keywords: railways, railway industry, digitalization, directions of scientific and technological development, transport.

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The current stage of development of the world economy is based on the paradigm of rooting the principles of a new technological paradigm and a significant increase in importance of information. Particular attention is paid to the quality of analysis of available information, including data enrichment and identification of significant causal relationships.

Knowledge and information are among key elements of the digital economy, which is widespread today in all the sectors of the economy and in social sphere. Mass digitalization affects the processes and mechanisms of functioning of the socio-economic relations regarding most aspects of life, including through development of integrated digital ecosystems [1].

There are series of different definitions of digital ecosystem and of ecosystem of digital economy [e.g., 2]. F. Nachira, P. Dini and A. A. Nikolai understand as a digital ecosystem a combination of information network, social sphere and knowledge sharing network [3]. E. Chang and M. West in their works defined a digital ecosystem as a domain of a cluster environment, including biological, economic, and digital species, as well as technical means [4]. H. Dong, F. K. Hussain extended a concept of a digital ecosystem to a concept of «digital artifacts» and infrastructure of data transmission, storage and processing, users of systems, including social, economic, political, psychological and other factors affecting implementation of interaction [5].

In modern realities, digital ecosystems involve active use of automation technologies and dominant role of information, which is a key factor in making managerial decisions. Digitalization opens new possibilities for analysis of information, its acquisition and processing, allowing to create more accurate predictive models and improve data quality [6].

These facts contribute to emergence of a network economy and a knowledge economy. Digitalization involves replacement of traditional tools for implementing various socio-economic processes with digital ones, because of which the environment of digital ecosystems is being developed [7].

It's worth stipulating that despite the active spread of the principles of digital transformation of the global economy and of the social sphere, empirical and research base allowing to assess the effects of implementation of the corresponding digital initiatives have not been equal to the scale of the tasks, both regarding economic aspects, and generalization of possible spheres of implementation of digital technology.

The *objective* of the article is to present the results of the three-level study of prospects for scientific and technological development of the railway industry in the context of digitalization of the economy based on application of the *methods of system analysis* to international expertise and practices. The first level of the assessment was to identify the main directions of development of digital technologies which can be applied to railway transport; the second level was focused on the analysis of strategic railway documents developed in some regions and by some international organisations followed by identification of key trends in digital development; the third one made it possible to identify the most effective information technologies to be implemented for railways, particularly in the Russian Federation.

1. Main directions of digital technology development

Among main objectives pursued by digitalization, it is worth highlighting the increase in operational efficiency of various business processes, including:

- increasing speed, quality and accuracy of the processes performed;
- minimizing the number of errors and their significance, leveling the human factor;
- identifying new cause-effect relationships and dependencies by processing large arrays of unstructured information and applying advanced data analysis algorithms;
- transfer of physical and material objects into a digital environment for subsequent remote control and monitoring in real world, etc.

In the Russian Federation, in accordance with the Decree of the President dated May 7, 2018 No. 204 «On national goals and strategic tasks of development of the Russian Federation for the period until 2024» (hereinafter – the Decree), one of the priority tasks is implementation of breakthrough scientific, technological and social economic developments, including development of the digital economy [8].

To achieve the objectives and targets set by this Decree, a system of national programs (projects) was developed, including the national program «Digital economy of the Russian Federation». The purpose of this national program is to provide necessary conditions for digital transformation of priority sectors of the economy and the social sphere, development and implementation of advanced domestic technologies and solutions created on the basis of «end-to-end» digital technologies (hereinafter – EDT), development of an integrated digital infrastructure and ecosystem [9].

In the framework of the federal project «Digital technologies» of the national program «Digital economy of the Russian Federation», special attention is paid to supporting development of EDT and their subsequent implementation in priority sectors of the economy and social sphere. The following are distinguished as EDT:

- quantum technologies;
- components of robotics and sensorics;
- neurotechnology and artificial intelligence;
- new manufacturing technologies;
- distributed registry systems;
- wireless technology;
- virtual and augmented reality technologies.

The priority areas for implementation of these technologies are industries that have a significant multiplier effect on other sectors of the economy.

One of such industries in Russia is the railway industry. According to the Strategy for scientific and technological development of Russia [10], the railway industry is one of the main elements of the transport system of urban agglomerations, it has the necessary innovative and scientific and technical potential for successful digital transformation. There are many researches devoted to that topic, and we also intend to address it in more details in further publications.

2. Strategic documents in the field of railway transport and key trends in digitalization: international experience

Digitalization in the railway industry is a complex, multifaceted process that affects various aspects of business processes and determines the direction of scientific and technological development. Despite the fact that development and implementation of digital technologies and solutions is not a core business for most railway companies, development of areas directly related to digitalization is today a major scientific and technological priority for the entire industry. A rough estimate of the growth of income of railway companies from introduction of advanced intelligent developments only in the field of rolling stock traffic control and signalling is 19 billion euros per year [11].

At present, regional and international organisations and associations have a great influence on scientific and technological development of the railway industry. Those organizations actively publish reports and White Books, which highlight the priority areas for development of the railway industry, strategies for scientific and technological development, challenges, and the most successful products and technologies. Such documents have a direct impact on the development vector of the entire industry. Among those documents we can cite:

- White Book of the European Commission «Towards a single European transport space – towards a competitive and resource-saving transport system» (hereinafter referred as EU White Book);
- White Book of Association of American Railways «Putting Technology to Work. How freight Rail Delivers the 21st century» (hereinafter referred as AAR White Book);
- EU Rail Transport Development Program Shift2Rail (hereinafter referred as EU Program).

EU White Book

Creation of a single European transport space, development of an integrated approach and common standards for controlling movement of rolling stock, organization of high-speed passenger and freight traffic, and development of multimodal (intermodal) transportation are highlighted among key priorities for development of the railway industry in the EU White Book [12].

In the context of digitalization of the railway industry, the EU White Book identifies the following areas of scientific and technological development:

- use of advanced intelligent control systems for the railway network and passenger mobility information system;
- creation of an intelligent system for selling tickets for combined modes of transport (organization of multimodal transportation);
- optimization of traffic schedules and traffic flows by applying TEN-T system to infrastructure;
- use of intelligent transport systems;

• deployment of Galileo European global navigation satellite system;

• use of detection and tracking technologies;

• development of technology for protecting confidentiality of personal data;

• security technology development.

AAR White Book

The Association of American Railways pays considerable attention to improving safety of railway networks, reducing the negative impact on the environment, and developing appropriate legislation and technology [13].

Most of these areas are provided with digital technology. The priority areas of digitalization highlighted by AAR White Book are:

• real time monitoring of infrastructure facilities;

• use of innovative monitoring technologies to improve quality of equipment maintenance;

• prevention of errors caused by the human factor;

• introduction of special software for monitoring, planning and accounting of fuel and energy costs;

• use of intelligent sensors as part of maintenance and repair processes;

• use of big data and artificial intelligence technologies;

• automation of production processes.

EU program

The EU program emphasizes the importance of digital transformation for creating cost-effective and reliable trains, the use of new running gears, braking systems, and development of modular train components. Considerable attention is also paid to creating an economical, efficient, environmentally friendly and reliable infrastructure with high throughput capacity [14].

The priority areas of digitalization in the EU Program comprise:

• automated train control;

• virtual coupling technology for wagons;

• cybersecurity;

• introduction of smart stations;

• introduction of smart energy supplies;

• increasing compatibility of various services;

• introduction of tracking technologies for movement of trains, passengers and goods;

• creation of «service assistants» for travel.

We would like to also highlight the Report of the International Union of Railways entitled «The Railway Operating Community (ROC) involvement in EU projects» (hereinafter referred as UIC Report). The UIC Report outlines the importance of developing multimodal transportation technologies and improving safety systems. A significant part of the UIC Report refers to development of energy efficiency technologies, increasing efficiency of power plants using hybrid technologies and energy storage systems and development of concepts for traction systems of the next generation [15].

Besides the indicated areas, the following digital solutions are highlighted in the UIC Report:

• research of automated, compatible and interconnected advanced traffic management systems;

• increasing capacity of railway by introducing automated train control systems;

• improvement and optimization of train tracking systems;

• development and application of monitoring systems and methods for collecting big data;

• increasing standardization and unification of information systems;

• development of intelligent passenger mobility management platforms.

Leading railway companies in the EU and USA are also actively implementing their own digital development strategies, identifying various advanced digital developments as their own priorities for scientific and technological development. However, it is worth noting that these strategies largely overlap and correlate with the above strategic development.

Table 1 generalizes key aggregated areas of scientific and technological development directly related to the digital transformation.

3. Priority technologies in the context of digitalization in the railway industry

Implementation of intelligent automation systems, optimization, and mechanization of internal business processes.

In this field, railway companies are actively introducing new means of interacting with customers in the digital environment. The most common way of digital interaction with a client is to create mobile applications. Their functionality allows electronic purchase and booking of tickets, laying of «door to door» routes using various categories of transport (buses, car sharing) [16].

Table 1

Aggregated directions of scientific and technological development of the railway industry in the context of digitalization

No.	Direction
1	Introduction of innovative systems for automation and mechanization of transportation processes
2	Resource, safety, risk and reliability management at different stages of the life cycle of railway facilities
3	Development and implementation of promising technical means and «end-to-end» technologies for railway transport infrastructure (railway automation and telemechanics, electrification and power supply, innovative information and telecommunication technology, etc.)
4	Development of transport and logistics systems in a single transport space

The use of digital technologies comprises introduction of smart tickets, which can be stored on the user's mobile device. Such tickets provide a single access to various modes of transport. Within the framework of mobile applications, a customer feedback system is implemented that allows companies to manage quality of the services provided [12].

To improve quality of user experience, «service assistants» are created. For travelers, these platforms provide opportunities to simplify «door to door» travel, to be escorted throughout the trip, considering personal preferences, solving unforeseen situations during the trip and simplifying interaction with various modes of transport involved in the process of travel. For commercial companies, these platforms make it possible to reduce time and money costs by forming the best route by analyzing a large number of parameters and selecting optimal values

The development and implementation of these platforms allows carriers to simplify the process of using company services by providing convenient user experience by analyzing big data, using artificial intelligence technologies, machine learning and providing recommendations for end users based on them.

One of the most important areas for modelling corporate-to-customer interaction is associated with predictive analytics and passenger traffic forecasting systems. Using these digital tools, it becomes possible to predict the magnitude of demand for transport services during a particular period by using big data technology. This technology is also used in implementation of dynamic pricing platforms.

The main effects of implementation of this area of digitalization are reduced time for data processing, increased fault tolerance, increased productivity and consumer loyalty.

Additional features include active use of business applications in internal processes, linking digital devices of employees into a single information network, using business intelligence software, stimulating the work of employees using digital tools.

Unlike existing solutions, these technological trends can provide the company with the maximum volume of information about its activities, which allows to increase labor productivity and effectiveness of internal interaction.

Resource, safety, risk, and reliability management at the stages of the life cycle of railway facilities using digital systems.

Active implementation of digital technologies not only opens new business opportunities, but also entails new risks associated with cybercrime. As part of ensuring information- and cyber-security, digital systems are being integrated into integrated automated systems, are subject to continuous software improvement, while introduction of monitoring, maintenance and remote configuration of digital systems and equipment, and use of cybercriminal countermeasures are expanded [17].

Specific security measures include user identification and authentication, firewalling, restricting user access, distinguishing between open networks, encrypting data transferred outside the controlled zone, logging user and administrator actions, regularly updating software and using an open software product, anti-virus protection of information resources, management of information security tools, use of the principles of majorization and reservations.

To reduce the impact of the human factor in emergencies, as well as to reduce injuries in production, modern technologies are used, including various navigation systems, which, in turn, are necessary to provide shunting automatic locomotive signalling systems (MALS) with shunt-time information. It is worth noting that improvement of traffic safety systems is based on creation of multi-level multifunctional systems for interval regulation of train traffic, interacting systems of automatic driving and diagnostics on rolling stock, which are inextricably linked with stationary automation, telemechanics, and information systems.

The sensors, digital means for monitoring the conditions of facilities, non-destructive testing technologies (without decommissioning the facility) are being actively introduced. Smart sensors, advanced analytical software and information exchange systems for monitoring equipment status in real time are being implemented. Implementation of high-precision coordinate systems, terrain design systems will allow monitoring the movement of high-speed trains. Also, laser and infrared detectors are placed near the railway track, evaluating the condition of axes and bearings of a moving train together with smart cameras.

Sensors to detect explosives, smart chips, and scanners are used as a means of ensuring passenger security at stations and in trains.

Digital terrain modeling is carried out by discrete scanning of the earth's surface. The real location of the object can be calculated due to a high-precision satellite receiver operating in a separate mode, synchronized with an inertial system. Having determined the rotation angles and relative deviations between the elements of the studied area, it becomes possible to identify the absolute coordinates of any point of laser reflection within the appropriate limits.

Automated monitoring of rolling stock maintenance will allow early detection of system malfunctions and maintenance errors. Monitoring, diagnostics, and monitoring the state of the infrastructure make it possible to identify in advance the precautionary states of track devices, power supply, automation, and telemechanics, and determine the causes of malfunctions [18].

Digital monitoring of railway facilities can increase safety, reduce the cost of the life cycle of rolling stock and infrastructure, reduce downtime of wagons, quickly identify and fix technical problems, distribute staff more efficiently, and increase economic and operational efficiency and labor productivity.

As part of digital transformation, introduction of smart power supplies is proposed, which develops systems for planning, rationing, accounting, and stimulating the saving of fuel and energy resources, as well as maximizing fuel efficiency. The implementation of these tasks is carried out by introducing and using special software that allows to control fuel consumption based on the real time analysis of many variables, in particular, of topography, track geometry, train mass and length, wind speed.

Development and implementation of advanced technical means and «end-to-end» digital technologies for rolling stock and infrastructure (railway automation and telemechanics, electrification and power supply, innovative information, and telecommunication technology, etc.).

The key decisions in this scientific and technological area are automated systems for building operational traffic schedules, route planning systems, digital platforms for providing multimodal (intermodal, combined) transportation, digital platforms for managing transportation processes, auto-driving (autonomous rolling stock), intelligent dispatch control systems, unmanned transportation control technologies processes, including loading/unloading processes, «machine vision» (technology segment of artificial intelligence, the essence of which is to obtain and process real images in order to solve applied problems without full-scale human involvement).

Auto driving will increase transit capacity by reducing the intervals between trains, and will also help reducing energy consumption by locomotives, due to the use of optimal algorithms and the absence of a human factor influencing rolling stock control. It should be noted that machine learning technologies using data from sensors are used to analyze the situation. Alternative technologies include high-precision locomotive positioning detection tools and an electronic 3D map.

Digital simulation systems for railway infrastructure are amidst key technologies for creating a new type of railway system due to the significant development of sensor technologies, the amount of processed information, and the computing power of computers. The technology is able to improve the operational activities of the railway company and is a key one, on a par with intelligent systems, that uses the Internet of Things to create an effective multimodal and intermodal logistics systems.

Intelligent systems using the Internet of Things in the process of monitoring the status of rolling stock and railway infrastructure [19], when successfully implemented in the operational activities of railway companies, will optimize maintenance. Subsequently, the successful implementation of IoT technologies will significantly automate the processes of rolling stock and railway infrastructure management.

Development of transport and logistics systems in a single transport and information environment.

Introduction of advanced information and communication systems is necessary to implement the process of developing transport and logistics systems in a single transport and information environment. These systems significantly accelerate the processes in the supply chain and allow real-time monitoring of the current state of the elements of the railway network.

The use of information and communication systems can simplify the process of short-term planning and booking schedule threads. These technologies make it possible to speed up the decision-making process by operators and to provide them with information regarding various parameters. The use of information and communication systems as a technological railway communication and data transmission channel allows to solve the problems of compatibility and safety of train traffic on railways.

In the process of introducing unified information and communication systems, processes of automation and simplification of dispatching work are achieved, which increase speed of processing requests, accuracy of the analysis of incoming information and safety of traffic management.

Besides information and communication systems, active implementation of intelligent integration technology platforms is also underway. It is purposed to create a single transport information environment that will allow carriers to have a complete understanding of the transportation process and make more efficient use of information on rolling stock. As part of implementation of this environment, carrier companies will have access to a centralized database with the necessary available information that can be used to make decisions, increase the efficiency of rolling stock operation, manage the company, which will result in lower costs, more efficient staff interaction.

Conclusions.

The above described digitalization trends in the railway industry are deepening thanks to the processes of globalization and internationalization of digital transformations in the field of doing business. The railway industry is becoming more open and seamless. Digitalization in the railway industry is carried out not only through introduction of new technologies, but also through rethinking traditional business models, by adaptation to the digital environment characteristic of the post-industrial economy.

It is possible to forecast that the results of application of economic forecasting methods and of a systematic analysis of forecasts of revenue growth from introduction of seamless technologies will witness a positive trend in development of the railway network technology market. The abundance of new products and solutions in the market indicates intensive digital transformation of the industry. An important feature of the applied and promising railway digital technologies is a high level of synchronization and mutual coordination of achievements from various fields, which allows obtaining a significant synergistic effect.

Most of modern digital technologies are already implemented or are scheduled to be implemented for railway transport in Russian Federation, and in JSC Russian Railways. However, dynamic developments of the digital systems will make railway organisations of all the countries consistently upgrade their assessments, prognostics, and action plans. So, regular analysis of best global practices, revealing prevailing trends, is a precondition for the railway companies could efficiently consider them while solving their tasks, specified by activity features and corporate strategy.

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