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# Critical Technologies in the System of Science and Technology Priorities of the Railway Industry: Global Experiences




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## ABSTRACT

*Critical technologies constitute key elements of any corporate development strategy for building an effective long-term research and technology system. The objective of the article is to analyze critical technologies in the system of science and technology priorities of railway companies. Besides describing the approaches to interpretation of the concept of «critical technology», the research based on the instruments of Gartner hype cycle, content analysis, case study, analyzes examples of the most significant cases of implementation of critical technologies in railway companies, reveals clusters of the most demanded critical technologies that can dramatically change the railway industry in the medium and long term. Those technologies comprise automation and mechanization of production processes; high-speed passenger and cargo transportation; resource, safety, risk and reliability management at all stages of the life cycle of railway transport facilities and infrastructure; development of transport and logistics systems within the single transport and information space; organisation of heavy haul cargo transportation.*

*The results confirm the need for regular monitoring and improving efficiency of organisation of technological (innovation) activity of railway companies in order to maintain their leading positions in terms of competitiveness.*

*Keywords: transport, railway, critical technologies, digital technology, science and technology priorities, science and technology development, Gartner hype cycle.*

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**Background.** Innovative and technological activity of railway companies is based on determination of critical technologies and solutions (technology development priorities) within the system of cross-cutting priorities for science and technology development. The accuracy and quality of planning roadmaps for their development, implementation and commercialization largely determine success and competitiveness in the long term [1].

Global practices reveal various approaches to determination of critical technologies. The origins of the term itself are usually associated with strategic core materials and technologies which were first called critical materials in the 20th century in the United States, and that were characterized by maximum efficiency in terms of functioning of the armed forces but were not produced in this country. In France, key (critical) technologies are strategic science and research fields for the French economy, determining national science and technology priorities and setting guidelines for science, technology and innovation policy [2–4].

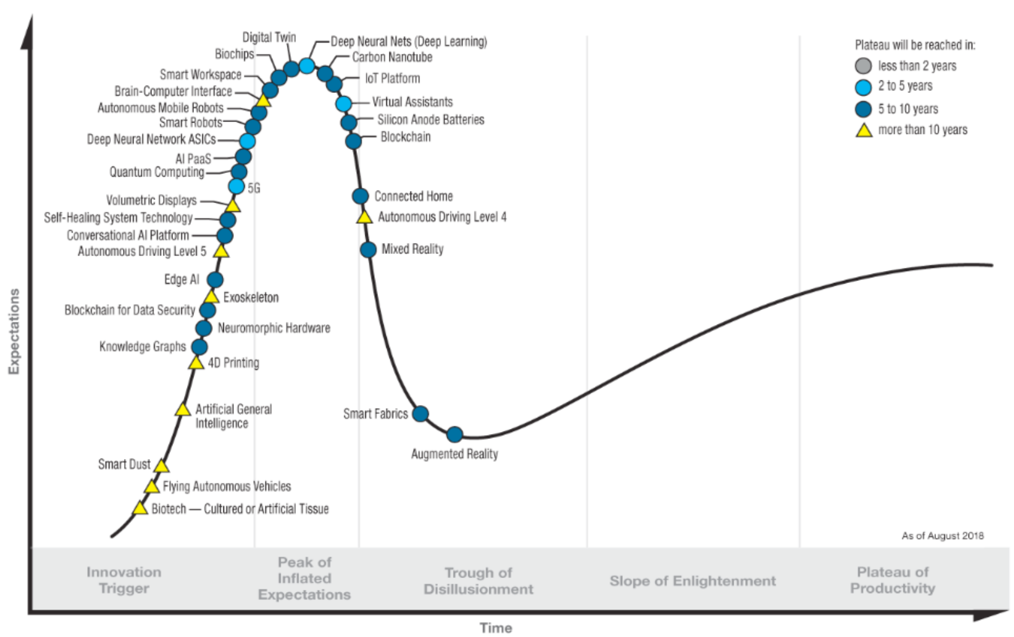
The task of their development is to determine a list of technologies that are essential for effective functioning of a company, industry or country.

In the Russian Federation, a list of critical technologies is an instrument of state strategic planning: critical technologies are national science and technology development priorities for the medium term (from three to ten years) [5, p. 64].

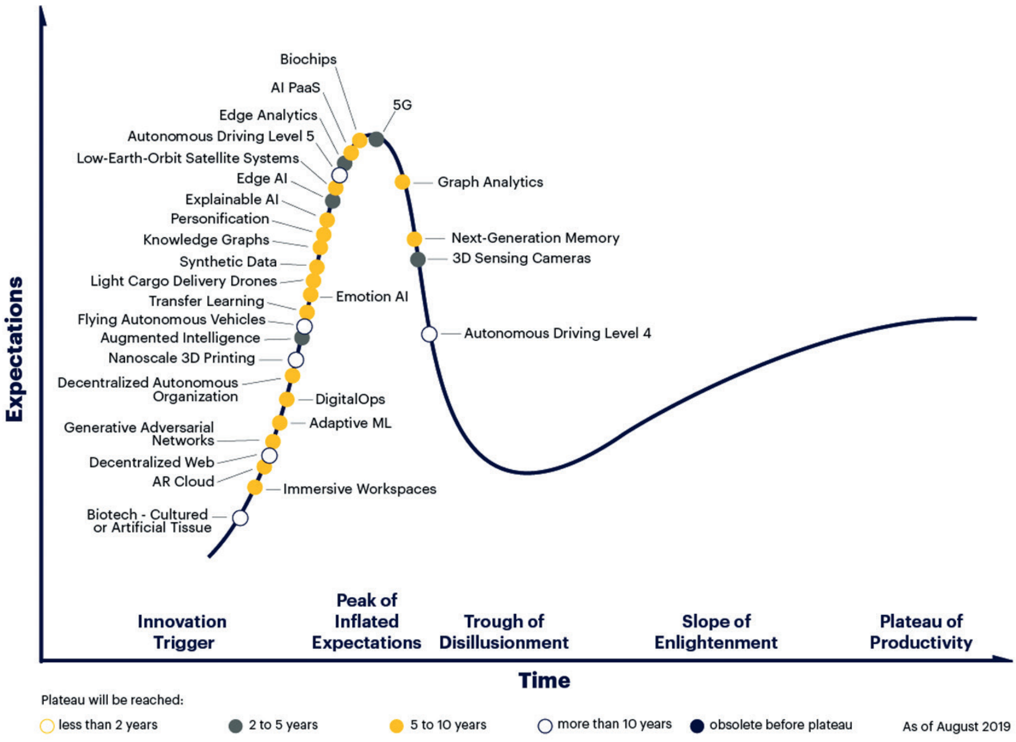
Critical technologies can also mean a complex of intersectoral (interdisciplinary) solutions that form prerequisites and foundations for long-term development of technology trajectories, characterized by the presence of an extensive spectrum of potentially significant and economically feasible ways of subsequent implementation of those solutions [6, p. 49]. Critical technologies have a significant potential impact on competitiveness of various sectors of the economy and the social sphere.

The emergence of critical technologies is traditionally associated with transition from a technology (renunciation of a technology) to a fundamentally new one, based on a different principle of operation, a physical effect, or other significant parameter characterizing this technology. Efficiency and quality (technical features, parameters and available functionality) of critical technologies predetermine their importance, making it necessary to give them paramount attention in the context of organizing technological (innovative) activities.

Usually, critical technologies mean breakthrough innovations and technologies (see, e.g. [7]) owing a potential to start a




***Pic. 1. Gartner hype cycle for Emerging Technologies. as of August 2018. Source: Gartner, Inc. Website [10].***




***Pic. 2. 2019 Gartner Hype Cycle for Emerging Technologies. Source: Gartner, Inc. Website [11].***

fundamentally new technology life cycle. Breakthrough innovations are not aimed at mere improving the existing situation, but at fundamentally changing the current market and replacing the existing technology.

The *objective* of the study is to analyze critical technologies within the system of science and technology priorities of railway companies using the *methods* of content analysis, case study, and Gartner hype cycle tools.

**Results.**

**Digitalization and Gartner hype cycles**

Global practices frequently depict the model of critical technologies in the context of full-scale digitalization of all aspects of the economy and social sphere with the help of Gartner hype cycle methodology, which represent a maturity cycle of key (emerging) technologies [see, e.g. [8, pp. 223–224; 9, p. 78]). This tool demonstrates maturity of digital technologies, as well as the general logic of their development in the context of the following key stages:

• innovation trigger (technological breakthrough, beginning of a technology development);

• peak of inflated expectations (a huge interest in a technology determines an extremely high offer, accompanied by a significant amount of fraud and failure);

• trough of disillusionment (technologies do not achieve the previously announced effects or parameters; technology companies fail in the process of a technology development);

• a slope of enlightenment (improvement and adaptation of technology, period of its cardinal revision and change of its focus within the framework of its development trajectory);

• a plateau of productivity (advantages of a technology become obvious and are recognized by all, the relevance of a technology is confirmed by the fact that a technology is in high demand).

A feature of this methodology is its positioning as of a descriptor of the life cycle of technologies, while the latter are not provided with absolute guarantee that all of them will finally reach the productivity plateau. Most digital technologies do not have the necessary potential to overcome the trough of disillusionment, which is determined by the lack of a real effect for the economy and business.

In 2018, Gartner hype cycle (Pic.1) depicted among other technologies approaching the peak of demand and characterized by inflated expectations regarding the significance and effectiveness for various sectors of the economy the following digital technologies:

• artificial intelligence, deep learning;

• robotics;

• industrial internet of things (IIoT) and digital twin;

• virtual assistants, etc.

The 2019 Gartner hype cycle has been updated, namely biochips, 5G, autonomous driving level 5 technologies have advanced on their route from innovation trigger phase to the peak of inflated expectations (Pic. 2).

Information technologies that determine possibilities of digital transformation are highlighted today by most industry companies, including railway ones, as critical. According to McKinsey, an international consulting agency, digital technologies are aimed at transforming every link in the company's production chain, from research and development to sales and service [12].

According to PWC consulting company, a significant share of companies' investments in development of critical digital technologies is aimed at improving operational efficiency, including (but not limited to) the fields of sensorics and communication devices, platform digital solutions, and intelligent production management systems [13].

In the railway industry, critical digital technologies are widely used in the framework of implementation of the concepts of «digital» railways, particularly for the tasks of infrastructure maintenance (see, e.g. [14; 15]), of high-speed rail and multimodal (intermodal) transportation (see, e.g. [16]).

**Railway critical digital technologies**

Leading railway companies identify various cross-cutting digital technologies used both for rolling stock operation and infrastructure facilities construction and maintenance as critical digital technologies defined within the framework of priorities for long-term science and technology development. The key areas of implementation of critical digital technologies in the railway industry are as follow [17]:

• automation and mechanization of production, operations and service processes;

• organisation of high-speed passenger and cargo transportation;

• development of transport and logistics systems within the single transport and information space (development of interoperability);

• resource, safety, risk and reliability management at all stages of the life cycle of railway transport facilities and infrastructure;

• organisation of heavy haul cargo transportation.

Considering fast development of technology, demonstrated particularly by annual changes in Gartner hype cycles, the above classification is suggested by the authors as an initial reference point, that does not exclude its further modification, updating, adaptation and specification, the use of other multiple existing approaches[1], particularly for solving strategic management tasks with regard to individual companies and processes.

Effective management of rolling stock and rail infrastructure under current conditions of development of information technology suggests the active use of automated and intelligent systems. Various leading railway companies, including (but not limited to) particularly China State Railway Group Co., Ltd. (China, hereinafter called CR), Deutsche Bahn Group AG (Germany, hereinafter – DB), Japan Railways Group (Japan, hereinafter – JR), Groupe SNCF (Société Nationale des Chemins de Fer Français, France, hereinafter – SNCF), Swiss Federal Railways (Switzerland, hereinafter – SBB), Austrian Federal Railways (Austria, hereinafter – ÖBB), Korean Railway Corporation (Republic of Korea, hereinafter – Korail), Canadian National Railway Company

[1] See, e.g., A Roadmap for Digital Railways, prepared in collaboration between the UIC and several European agencies and bodies. [Electronic resource]: http://www.cer.be/sites/default/files/publication/A%20Roadmap%20for%20Digital%20Railways.pdf; numerous valuable publications in the framework of EU Shift2Rail project. [Electronic resource]: https://shift2rail.org/, e.g., the report Digital Transformation of Railways. [Electronic resource]: https://shift2rail.org/wp-content/uploads/2018/04/DIGITAL_TRANSFORMATION_RAILWAYS_2018_web.pdf and other papers; the Thales group publication on Digital Transformation in The Railway Industry. [Electronic resource]: https://www.thalesgroup.com/en/germany/magazine/digital-transformation-railway-industry; and many other publications.

**Table 1**

**Pilot system of automated driving for high-speed electric trains**

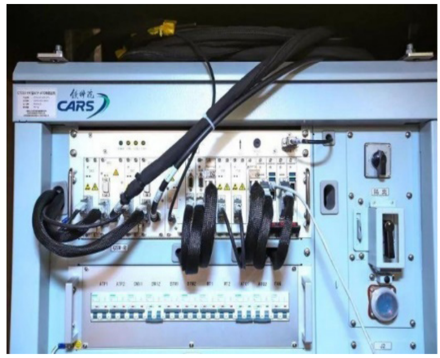
| | | |
|---|---|---|
| CR (China) | 中国国家铁路集团有限公司 CHINA RAILWAY | Automated driving system for high-speed electric trains |
| Intelligent control system for high-speed electric trains of CR is the latest system to optimize route and speed in real time based on a significant number of external parameters. The first successful field test trials of the system were carried out in June 2018 at Beijing–Shenyang section: the maximum rolling stock speed during the test attained 350 km/h. | |  |
| Technology readiness level (TRL) – 8 [1] (Technology verification/ driving) | | |
| Functionality | This system allows to automatically start movement, maintain given speed and make stops at a platform, including automatic opening/closing of doors. | |
| Effects | • improved consumer experience;<br>• increased railway safety;<br>• increased labour productivity. | |
| Similar cases | DB, FERROVIE DELLO STATO ITALIANE, SNCF, JR | |

**Table 2**

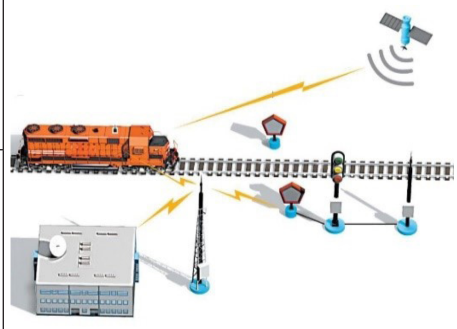
**Multifunctional interval train traffic control system**

| | | |
|---|---|---|
| DB (Germany) | DB | Multifunctional interval train traffic control system |
| The DB has introduced the European train control system (hereinafter – ETCS), which is a set of common standards developed as part of international cooperation for railway automation, telemechanics (teleautomatics, automatic remote control), communications and dispatch control.<br>ETCS eliminates differences in incompatible signaling, interlocking and block control systems, providing unhindered and safe rail transportation. The system is a cloud infrastructure railway network management system. | |  |
| TRL 9 (Introduction of the technology in operations) | | |
| Functionality | The main components of ETCS are:<br>a) eurobalises – autonomous transceiver devices (transponders) with non-volatile memory, placed between rails and designed to exchange data with rolling stock;<br>b) Euroloop – cable data transmission system;<br>c) track electronic unit;<br>d) on-board equipment.<br>Interval control algorithms use a coordinate considering the maximum confidence interval. To increase the accuracy of positioning of rolling stock, the International Union of Railways (UIC) and the European Space Agency have developed and implemented a technology for combining data received from balises and from navigation satellites. | |
| Effects | • improved operational efficiency;<br>• increased railway safety;<br>• improved service quality;<br>• reduced costs of the life cycle of rolling stock and infrastructure facilities. | |
| Similar cases | SNCF, FERROVIE DELLO STATO ITALIANE, ÖBB, SBB | |

[1] Here and below: technology readiness (maturity) level as estimated according to GOST R [Russian state standard] 58048-2017.

**Table 3**

**Integrated operational monitoring of rolling stock and high-speed traffic infrastructure**

| | | |
|---|---|---|
| CR (China) | 中国国家铁路集团有限公司 CHINA RAILWAY | Technologies for integrated operational monitoring of rolling stock and high-speed traffic infrastructure using satellite and geoinformation technologies |
| CR together with Huanwei telecommunications company are testing the platform system built following the principles of industrial Internet of things on Beijing–Tianjin railway: it is planned to equip the most loaded sections with Huawei's wireless LTE data transmission systems and to subsequently integrate them with sensor modules and RFID tags. | |  |
| TRL 8 (Technology verification/piloting) | | |
| Functionality | The use of machine learning algorithms and predictive analytics allows scenario-based simulating to predict errors and malfunctions for planning maintenance and repair of rolling stock and infrastructure facilities. | |
| Effects | • increased railway safety;<br>• improved service quality;<br>• increased labour productivity;<br>• reduced costs of the life cycle of rolling stock and infrastructure facilities. | |
| Similar cases | DB, JR, KORAIL, SNCF | |

(Canada, hereinafter – CN), Network Rail (the United Kingdom, hereinafter – NR), the Ferrovie dello Stato Italiane (Italy), as well as transportation units of the Rio Tinto Corporation, regularly implement innovative projects aimed at introducing advanced technologies and solutions in order to improve quality of passenger service, maintenance of rolling stock and infrastructure facilities.

The cases described further on in the framework of suggested classification are mainly based on the information retrieved from the websites of the mentioned companies.

**Automation and mechanization of operations processes**

Pursuing the goals of increasing operational efficiency and competitiveness, railway companies are taking measures to increase the level of technological development in various areas of activity. Thus, development and implementation of intelligent technologies for information and control support for rolling stock management [18; 19] and of remote dispatch control systems is among most highly demanded science and technology developments for the railway industry in the field of automation of operations processes in the medium term. The Table 1 depicts one of the most significant examples of introduction of autonomous driving systems for the rolling stock.

Automation and mechanization systems for operations processes also have a significant positive effect on the level of safety and reliability by reducing influence of the human factor on various processes, including those characterized by a large number of repetitive algorithmized actions that can be replaced by advanced automated technological solutions. Relevant cases regarding such technologies can be illustrated at the example of introduction of additional systems of control of maintenance employees, as well as of the use of multi-functional systems for interval regulation of trains traffic (Table 2).

Active use of automation technologies in the railway industry is carried out, inter alia, for the following purposes:

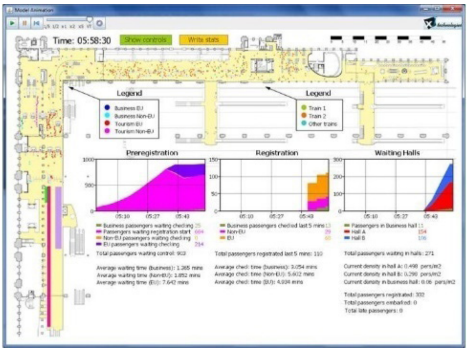
• control over transportation of goods (including container and piggyback (contrailer) transportation);

• alerting of teams and management of track repair machinery operation;

• prompt transmission of information in case of emergency.

**Table 4**

**Simulation modelling of interaction of rolling stock and high-speed traffic infrastructure**

| | | |
|---|---|---|
| SNCF (France) | SNCF | Simulation technologies with regard to interaction of rolling stock and high-speed traffic infrastructure to ensure energy efficiency and safety |
| SNCF Gares & Connexions commissioned its subsidiary AREP and EMSYSS simulation consultancy company, to develop a model to optimize the use of Transmanche terminal at Paris North Station. Technical implementation of the model fell on AnyLogic company. The main objective of the project was to reduce waiting time at passenger checkpoints. The developed and implemented model allows to assess possible difficulties in such zones and to propose various scenarios for their prevention. | |  |
| TRL 9 (Introduction of technology into operations) | | |
| Functionality | Modelling of various processes at the terminal checkpoints became possible thanks to the unique technical and functional properties of AnyLogic software. Simulation of such processes allows to find a solution for the problem of optimizing the cost of terminal operations while improving quality of services provided to passengers. | |
| Effects | • improved of passenger service quality;<br>• improved transportation safety. | |
| Similar cases | DB, NetworkRail, JR | |

**High-speed passenger and cargo transportation**

Organisation of high-speed rail traffic involves the use of technologies and platform solutions that are different from those used for traditional transportation. Digitalization and advanced information developments can increase efficiency and profitability of this type of passenger and cargo transportation, which has been till now associated with high costs.

The prospects for optimizing an integrated high-speed rail network are directly related to accuracy, completeness and reliability of information about each fast speed or high-speed main line. The optimal use of available resources is only possible through availability of comprehensive data on the object of study, which is achieved through introduction of various technology solutions, for example [16; 17] of the technology for integrated operational monitoring of rolling stock and high-speed

**Table 5**

**Single information and communication system for managing the transportation process**

| | | |
|---|---|---|
| DB (Germany) | DB | Single information and communication systems for managing the transportation process |
| Route planner system is designed to simplify short-term schedule planning. It is an intelligent integrated rail network management system that operates using a variety of digital technologies, including big data, cloud computing, artificial intelligence, etc. | |  |
| TRL 9 (Introduction of technology into operations) | | |
| Functionality | The introduction of this system provides train operators with quick solutions in response to requests from drivers and allows to quickly provide information about the estimated transit time. | |
| Effects | • increased railway safety;<br>• improved service quality;<br>• reduced costs of the life cycle of rolling stock and infrastructure facilities | |
| Similar cases | SNCF, SBB, ÖBB, NetworkRail, CN, KORAIL, Ferrovie dello Stato Italiane | |

**Table 6**

**Multifunctional system of control of technical equipment on the basis of the assessment of its actual condition**

| | | |
|---|---|---|
| NR (Great Britain) | NetworkRail | UAV for infrastructure condition monitoring |
| NR uses drones to assess the condition of the railway track and increase promptness and efficiency of search for damaged sections. | |  |
| TRL 8 (Technology verification/piloting) | | |
| Functionality | The cameras installed on the used drones have a viewing angle of 360° | |
| Effects | • increased railway safety;<br>• optimized maintenance and repair processes;<br>• increased labour productivity. | |
| Similar cases | DB SNCF CN | |

**Table 7**

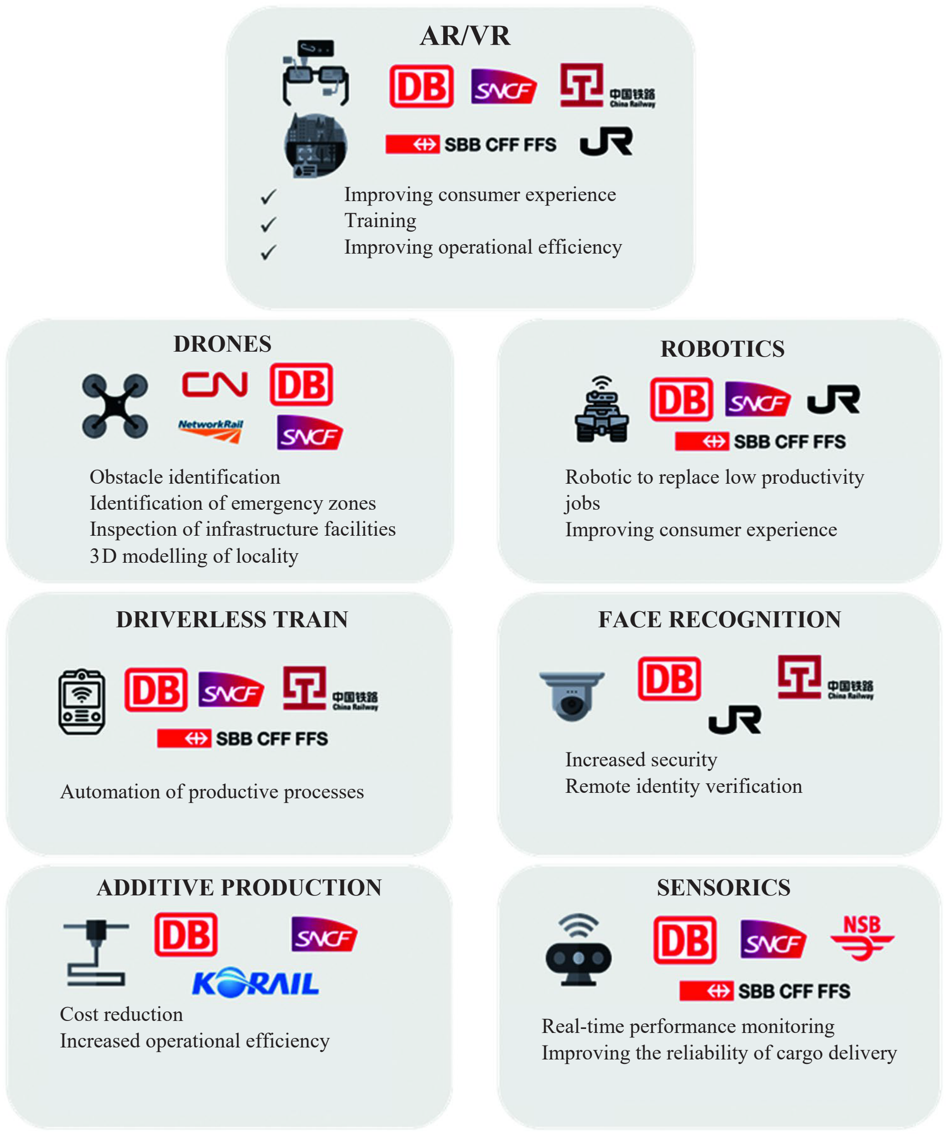
**Automated heavyweight rolling stock**

| | | |
|---|---|---|
| RioTinto (Australia) | RioTinto | Autonomous cargo heavyweight rolling stock |
| RioTinto corporation, as part of AutoHaul program (automation of trains carrying iron ore), has successfully introduced a fully automated long-haul heavy weight rolling stock in Western Australian Pilbara region, which carries out cargo transportation in the automated driving mode. | |  |
| TRL 9 | | |
| Functionality | Rolling stock, consisting of 3 locomotives, transports 28 thousand tons of iron ore over more than 280 km. Locomotives are equipped with on-board cameras allowing continuous monitoring of train movement from the control center. | |
| Effects | • increased railway safety;<br>• reduced life cycle costs of rolling stock and infrastructure facilities;<br>• increased labour productivity. | |
| Similar cases | – | |

traffic infrastructure using satellite and geoinformation technologies (Table 3).

Such systems help railway companies to consider loading of sections, find and use free transit capacity, and identify the relationships between various elements of the transportation process. They also have as one of the effects the rapid troubleshooting regarding technical faults, which has a positive impact on reducing downtime of rolling stock.

Digital transformation and intensive development of digital technologies also predetermine the possibility to increase energy efficiency of high-speed railway transportation. The development of such technologies is significantly accelerated by advances in the field of wireless communications and data transmission, which allow high speed data processing. Table 4 presents the case of the use of technologies of simulation modelling of




***Pic. 3. Critical railway digital technologies developed and/or implemented in leading companies.***

interaction of rolling stock and high-speed traffic infrastructure to ensure energy efficiency and safety.

Development of transport and logistics systems within the single transport and information environment

Information systems and platform solutions that integrate various databases and provide conditions for organizing transportation using various modes and categories of transport have a significant impact on the whole transportation sector. Relevant technological solutions greatly accelerate organisation, booking and tracking processes within the framework of transportation. Sensorics elements in conjunction with wireless technology and IIoT technology allow real-time monitoring of the current state and status of all the elements of the transport ecosystem.

These technologies are critical for various segments of the transport industry, including railway transportation. Particular attention is paid to the processes of development and implementation of single information and communication systems for managing transportation processes (Table 5).

The implementation of such systems comprises processes of automation and simplification of dispatching work, resulting in increase in speed of processing requests, accuracy of analysis of incoming information and safety of traffic management [19].

Resource, safety, risk and reliability management at all stages of the life cycle of railway transport facilities and infrastructure

Leading transportation companies regularly improve existing management systems directly related to management and monitoring of safety and reliability of railway transportation. Research and developments aimed at achieving more advanced technological solutions are conducted by research institutes and R&D departments on a permanent basis. This field of science and technology development englobes critical technologies that comprise integrated support systems for making managerial decisions to meet reliability and safety requirements for operation of technical equipment in railway transport.

Most of leading railway companies focus their attention on implementation of systems for monitoring and maintenance of technical equipment based on their actual condition monitoring and on forecasting of their operational life using predictive modelling [20], particularly, developing monitoring technologies with the help of unmanned aerial vehicles (UAV) (Table 6).

**Organisation of heavy haul cargo traffic**

Heavy haul cargo transportation as a promising direction for development of the railways involves the use of both updated technical solutions and information technologies. The Rio Tinto corporation, one of the leaders in the field of heavy haul railway transportation, operates a fully automated heavy haul rolling stock using autonomous driving technologies (Table 7).

**Conclusion**

Leading railway companies, within the framework of their activity, develop and implement various critical digital technologies that can be systematized into key groups of digital solutions, most of the technologies and solutions are mainly of an interdisciplinary nature.

Most demanded railway critical digital solutions can be highlighted as follows:

• Internet of Things technologies used for condition monitoring of rolling stock and infrastructure and for predictive analytics in order to increase efficiency of maintenance;

• machine vision used to detect various obstacles and accidents along the railway track;

• application of big data technologies in order to optimize the railway network;

• use of chat bots to improve quality of passenger service and improve consumer experience;

• digitalization (automation) of operational and business processes, including:

a) cloud infrastructure for management of the railway network and infrastructure facilities;

b) automation of control and maintenance of rolling stock;

• digitalization of container cargo transportation;

• use of procedures training devices for training corporate employees, including drivers.

Pic. 3 presents the most sought-after critical digital technologies that can dramatically change the railway industry in the medium and long term [16; 17; 21–23]. Most of these solutions correspond to the paradigm of digital transformation of companies, as well as of new and promising markets with a high share of added value, including the science, technology and innovation markets.

These critical digital solutions are characterized by the following parameters:

• use of «end-to-end» digital technologies;

• automation of productive and business processes;

• increased reliability and safety;

• improved operational efficiency.

In the context of the shortened technological cycle, a list of breakthrough, potentially critical and critical digital technologies is constantly updated. This fact determines the need for regular monitoring and improving efficiency of organisation of technological (innovation) activity of railway companies in order to maintain their leading positions in terms of competitiveness.

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