DIGITAL RAILWAY: PRINCIPLES AND TECHNOLOGIES

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ABSTRACT

The article is devoted to the study of a digital railway as of a complex technical and technological system having a connection with the digital economy. The main technological components of the digital railway are shown. The principles of block management, principles of radio monitoring, interdependence of digital logistics and digital railway are described. The role of cyber physical systems in development of the digital railway, the prospects of digitalization in ensuring safe automation and seamless integration of all modes of transport are emphasized.

Keywords: transport, management, digital railway, complex systems, digital economy, digital logistics, digital models, block management.

Background. *Digital technologies rebuild many industries, including business, transportation and logistics [1]. The digital railway is one of the consequences of emergence of the digital economy. In this case, the terminological feature should be noted.*

Some Russian terms [originally cited in Russian] correspond to the English digitalization. In Russia, the term «digitalization» [Russian transliteration of English digitalization] is standardized in GOST R52438–2005. In the digital economy, the term digitization is used, which literally means «transforming into digital form». However, in the field of economy and transport, it has another Russian equivalent, a non-standardized term [russified equivalent of both digitalization and digitization that makes no substantial difference between both terms]. From the point of view of linguistics, this is wrong, but from the technological point of view it is permissible and justifiable. Admissibility is due to the fact that classical digitalization involves obtaining discrete information for processing it on a computer and storing it in a database. That is a fairly simple and narrow concept.

The last term in the primary source has a broader meaning, but many Russian publications treat it meaningfully as digitalization, what makes the term meaningless[1]. The digital railway as a technology has arisen and is developing not isolated, but along with the technologies of digital transport [2], digital logistics [3], digital communication [4], digital business [5] and so on up to cyber physical systems [6].

As the essence, the digital railway (DR) is a complex system containing complex technological systems [7], complex technical systems [8], information processing systems, communication systems, navigation systems [9], technologies of Internet of things [10] and other structural elements. Therefore, from the system positions it is possible to characterize DR as a complex technical and technological system. As a phenomenon it is connected with the digital economy and it is from its features that many features of DR derive.

Objective. *The objective of the authors is to consider principles and technologies of digital railway.*

Methods. *The authors use general scientific and engineering methods, comparative analysis, evaluation approach.*

Results.

Digital economy as a methodological basis

The new economy arose after the fourth information revolution [11], which was also called «digital». Some people consider the economy associated with the digital revolution as new or networked. However, in 1994 Don Tapscott in the book «The Digital Economy. Promise and Peril in the Age of Networked Intelligence» [12] singled out the digital economy from the previous network economy. And it can be considered as a cluster and a result of development of a new economy. It should be noted that during three subsequent years (1995, 1996, 1997) Tapscott wrote three more books with exactly the same name. He updated and modified each of them, but the basic principles stated in [12] remained unchanged.

Principally, in his book, D. Tapscott gives 12 themes that differentiate digital economy from the old ones: knowledge, digitization, virtualization, molecularization, internetworking, disintermediation, convergence, innovation, prosumption, immediacy, globalization, discordance. These themes are accepted by the world community and have not caused criticism till now.

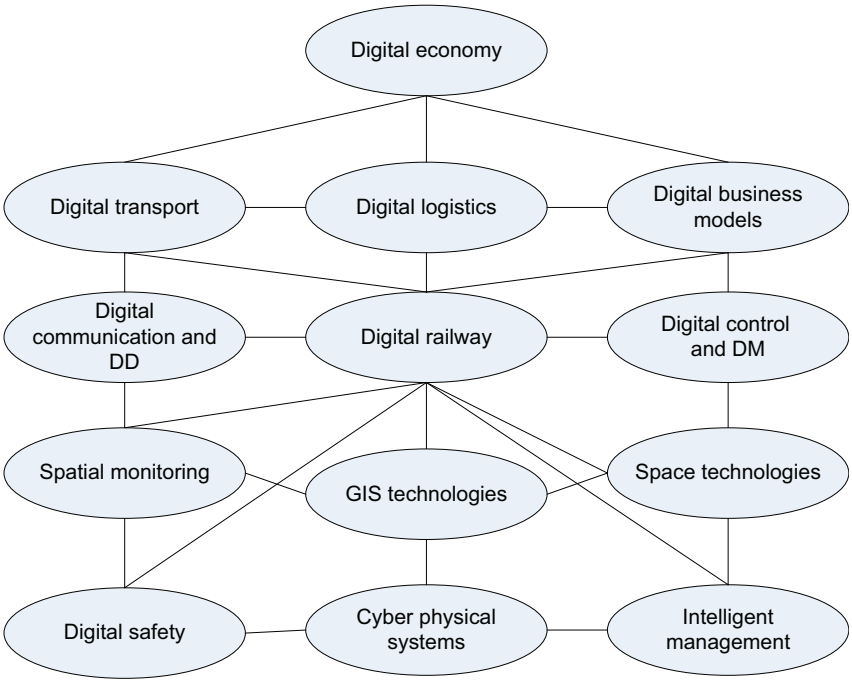
Let us dwell on those features that are relatively rare in the Russian-language literature. The most important term is digitization. The key difference in this term is knowledge.

Digitalization is a group of technologies through which knowledge can be stored digitally. In the old economy, where the information remained analog or physical, communication was possible only thanks to the actual movement of people. In the new economy, the digital form provided by digital devices allows the huge amount of information and knowledge to be freely transferred in the shortest possible time between people in different parts of the world.

Virtualization in the digital economy means a set of technologies that can be used to turn physical and material things into virtual ones. This ensures the compression of information and the cognitive effect of visibility and perceptibility [13] of large amounts of information, which in conventional technologies create an information barrier for a person.

Molecularization is a metaphorical concept, that traditional organizational structures give way to a more flexible and shallow structure. Project teams are the norm when people from all corners of the world come together. In the new economy, this will be a «bright organization» that will live through «heavy organizations», for which it is more difficult to change and adapt to static conditions. Startups can serve as an example of molecularization.

[1]On the whole the authors are dealing with specific Russian context of terms of digitization, digitalization and digital transformation, which is close e.g. to the positions described in Jason Bloomberg's paper «Digitization, Digitalization, And Digital Transformation: Confuse Them At Your Peril» (https://www.forbes.com/sites/jasonbloomberg/2018/04/29/digitization-digitalization-and-digital-transformation-confuse-them-at-your-peril/#53bcb6cb2f2c). Further approach of the authors to digital railway is described rather in terms of digital transformation. Ed. note.



Pic. 1. Place of the digital railway among complex technical and technological systems.

Disintermediation is a process in which the actions of intermediaries are significantly reduced. An example is a stock-free trade or Internet trading. This process requires a closer and immediate connection of enterprises with consumers.

Convergence is the name for the dominant sector of the economy, which is created by convergence of computing, communication and content.

Prosumption is a process that replaces the mass production of the traditional economy by the mass tuning or adjustment of (computer) products to the digital economy, blurring the differences between producers and customers. However, it requires a high information culture from the client. For example, various state electronic services, the purchase of electronic tickets and registration through a computer are not available to persons who have not got computer training. At the same time, each consumer becomes a member of the information main line, creating and sending a message to order a product or expressing his opinion about the product or service that he buys.

Discordance is a negative process associated with stratification of customers on the basis of information culture. Any new phenomenon comes across the resistance of the environment, of a part of society and a slow adaptation to it. As a result, technological conflicts arise. The gap between technologically literate «propertied» and technologically illiterate «underprivileged» is growing and can cause serious problems for society in the near future. Changes in the economy make it possible to create new types of organizations, where the use of information technology to work in the field of knowledge will increase the effectiveness of consumers and the effectiveness of organizations.

Place of DR among complex systems

As a complex technical and technological system, DR is connected and interacts with other complex systems and directions [14] (Pic. 1).

The digital economy serves, as already stressed, as a methodological basis of DR. Digital transport [2] is a more general concept and includes DR. At present, there is a need for a common transport policy [15] and this requires that DR is complementary to other types of digital transport. As a reflection of this fact, the European Railway Traffic Management System (ERTMS), including the European Train Control System (ETCS) and GSM-R mobile networks for providing communication between trains and moving blocks has been established in the European Union [16]. In practical terms, DR is subordinated to the interests of digital logistics [3] and digital business [5].

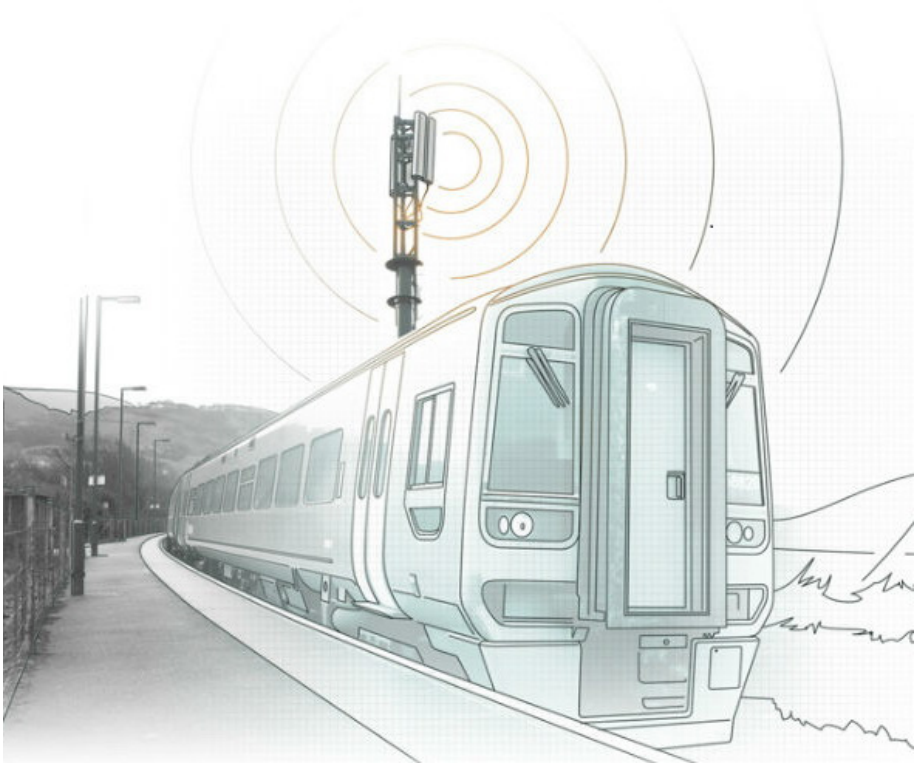
Digital communication [4] is mandatory for DR. Its feature is that it creates the possibility of radio monitoring in addition to video surveillance in conventional transport. The digital railway requires a new digital (information) control technology [17], and as a spatial object requires the use of geoinformation technologies, space monitoring technologies and integrated spatial monitoring [18]. Many situations of management of DR exclude the possibility of an immediate reaction of a person, therefore, elements of intellectual control or intelligent transportation systems are becoming more widespread.

Digital communication actualizes the problem of information security in two aspects: unintentional human errors and targeted sabotage or external threats. For an effective information security policy and to reflect external and internal threats, cyber physical systems are widely used.

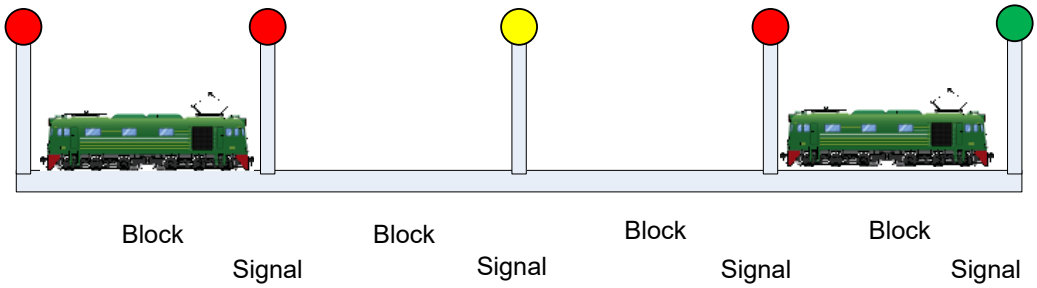
Some technological solutions

Radio monitoring. *Pic. 2 explains its essence. To implement the technology, the entire railway track must be equipped with radio monitoring stations, so that a mobile object is always in the observation zone.*

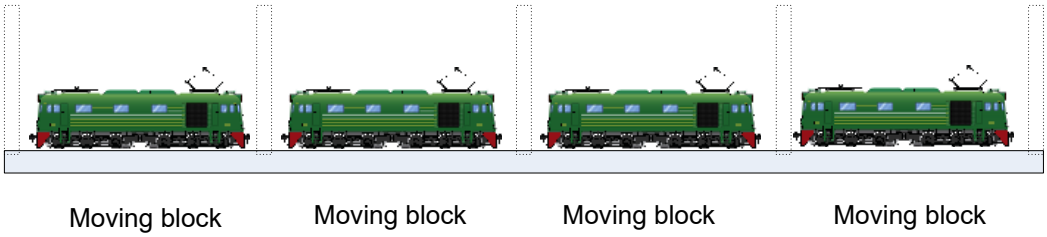
This is the technology of ground-based monitoring and it is not connected with satellite navigation, but complements it. In Russia, such radio control exists



Pic. 2. Technology of radio monitoring.



Pic. 3. The principle of conventional traffic.



Pic. 4. The principle of using moving block signaling.

in specially protected areas. Therefore, it is not difficult to extend this technology to the railway. Radio monitoring includes the direction-finding of a mobile object [19], taking into account its movement along a track, the digital model of which is known.

To implement this technology, vehicles and even each car must be additionally equipped with radio-frequency tags in addition to GPS/GLONASS receivers.

Moving block signaling technology. *This technology is explained in Pic. 3 and 4. Conventional motion can be defined as a signal-block movement. Moving trains are located within the range of blocks, motion over which is allowed by optical signals and*

Pic. 4. Application of UAV for loading and unloading operations.

additional signals. If the signal is permissive, then motion occurs. If the signal is restrictive, a vehicle does not move.

In moving block signaling technology (Pic. 4), a mobile object contains an internal information-computing system [16] and represents for other objects a system that carries out information interaction [20] with other objects.

The system of moving signal blocks is identified in real time by computers in the form of safe zones around each train [16]. A moving block allows trains to approach each other, while maintaining the required safety limits, thereby increasing the overall line capacity. The identification of the block requires knowledge about exact location of the train, as well as about the speed of all trains at any time and the constant communication between the central signaling and the driver's compartment signaling system. This is called integrated or integral control. In a digital aspect, such a mechanism involves the transition from pointed digital objects models to interval ones, which are described in [21].

A moving block effectively maintains a safe «envelope» of an empty track around each train (Pic. 4), which moves with it. This envelope can be adapted to match the train speed, optimizing the line capacity in different situations.

Digital logistics

Digitalization is one of the main priorities for the railway sector and its future. The challenge is to offer the customers highly effective and attractive transportation options and make the most of the opportunities offered by digital conversions. The growth of digital data leads to the need to increasingly use the Big Data technology [22], analyze information, optimize its activities, supply chain.

Automating the construction of the supply chain and optimizing the incoming and outgoing cargo movements allow rational use of available resources, to reduce waste. Mobile solutions provide greater transparency of operations. The digital inventory and supply chain management system facilitates end-to-end visibility for inventory, orders and deliveries.

Along with Big Data, the business has a new term called «data richness». Logistics companies use richness of data related to the movement of their goods and trucks to identify models that meet customer trends and to find what works well to gain competitive advantage.

Logistic companies resort to digital technologies not only to increase the efficiency of operations, but also to analyze operations and transform them. The use of robots in large warehouses and when handling dangerous goods is already widespread, as well as are the practices to do without a driver operator, using remote control.

The next important detail in digital logistics is the use of drones [23], especially for last mile delivery of cargo. The US government has already launched a pilot traffic monitoring system based on unmanned aerial vehicles. In countries such as Spain, France, the Czech Republic, there are several research projects that study the capabilities of aircraft drones to control traffic. Their use will significantly speed up the work, reduce difficulties, stress and inefficiency (Pic. 5).

For example, AmazonPrimeAir already carries out shipping [23] with unmanned aerial vehicles in less than 30 minutes after customers placed the order. When this technology becomes widespread, logistics will change significantly.

As a matter of discussion

In a number of works, DR is mistakenly called a model. This is a real technical and technological system, and the digital railway management system can be considered as a complex organizational and

technical system [14]. It is incorrect to reduce a complex system to a model.

Often in the materials about DR the authors do not pay due attention to data organization technology, although according to ISO/IEC9126–1. 2001 and GOST 28195–89, the organization of data is one of three components of the quality of any information system. Information systems as a part of DR are an element of paramount importance, with key functions.

As for Russian conditions, the so important factor of coordinate transformations is missing to some extent. For small countries such as Great Britain, this problem does not exist. For countries with a large territory, zonal transformations become a prerequisite for exact location of a vehicle in a single coordinate environment. The problem of a single time is also connected with it.

Conclusion. *Digitalization [in the meaning of digital transformation – ed.note] can and should ensure the safe automation and seamless integration of all modes of transport, as well as growth in carrying capacity and quality of various modes of transport.*

Internet of things contributes to highly integrated solutions that are convenient for transport management, which helps to realize the project of DR and digital logistics. IoT applications in digital logistics are widely used: from tracking of transport goods with controlled temperature conditions to ensuring the correct delivery of the package to the right place at the specified time. It is advisable to implement the project of DR as a project of a complex integrated system with inclusion of cyber physical systems.

REFERENCES

1. Zamyshlyaev, A. M. Evolution of digital modeling [*Evolyutsiya tsifrovogo modelirovaniya*]. *Nauka i tehnologii zheleznyh dorog*, 2017, Iss. 1, pp. 82–91.

2. Keck, W. H., Emberson, D. A. Posting status data in digital transport stream processing: US patent 7817721, 2010.

3. Digital transformation in transportation and logistics. [Electronic resource]: https://www.i-scoop.eu/digital-transformation/transportation-logistics-supply-chain-management/. Last accessed 11.02.2018.

4. Sneps-Sneppe, M. [*et al*]. Digital Railway and the transition from the GSM-R network to the LTE-R and 5G-R-whether it takes place? *International Journal of Open Information Technologies*, 2017, Vol. 5, No. 1, pp. 71–80.

5. Brousseau, E., Pénard, T. The economics of digital business models: A framework for analyzing the economics of platforms. *Review of network economics,* 2007, Vol. 6, No. 2, pp. 81–114.

6. Khaitan [*et al*]. Design Techniques and Applications of Cyber Physical Systems: A Survey. *IEEE Systems Journal*, 2014, Vol. 9(2), pp. 1–16. DOI: 10.1109/JSYST.2014.2322503.

7. Buravtsev, A. V. Complex technological systems [*Slozhnie tehnologicheskie sistemy*]. *Slavyanskiy forum*, 2017, Iss. 3, pp. 14–19.

8. Tsvetkov, V. Ya. Complex technical systems [*Slozhnye tehnicheskie sistemy*]. *Obrazovatel'nye resursy i tehnologii*, 2017, Iss. 3, pp. 86–92.

9. Rozenberg, I. N., Tsvetkov, V. Ya., Romanov, I. A. Railway management on the basis of satellite technologies [*Upravlenie zheleznoi dorogoi na osnove sputnikovyh tehnologii*]. *Gosudarstvenniy sovetnik*, 2013, Iss. 4, pp. 43–50.

10. Deshko, I. P., Kryazhenkov, K. G., Tsvetkov, V. Ya. Devices, models and architecture of the Internet of things: Study guide [*Ustroistva, modeli i arhitektury Interneta veshchei: uchebnoe posobie*]. Moscow, Max Press publ., 2017, 88 p.

11. Polyakov, A. A., Tsvetkov, V. Ya. Applied Informatics [*Prikladnaya informatika*]. Moscow, Yanus-K publ., 2002, 392 p.

12. Tapscott, D. The Digital Economy. Promise and Peril in the Age of Networked Intelligence. McGraw-Hill Published, 1994, 368 p.

13. Tsvetkov, V. Ya. Cognitive management: Monograph [*Kognitivnoe upravlenie: monografia*]. Moscow, Max Press publ., 2017, 72 p.

14. Buravtsev, A. V. Functioning of a Complex Organizational and Technical System in the Transport Sphere [*Funktsionirovanie slozhnoi organizatsionno-tehnicheskoi sistemy v transportnoi sfere*]. *Nauka i tehnologii zheleznyh dorog*, 2017, Iss. 3, pp. 48–58.

15. Rozenberg, I. N. On a Unified Transport Policy [*O edinoi transportnoi politike*]. *Nauka i tehnologii zheleznyh dorog*, 2017, Iss. 1, pp. 22–26.

16. A digital future for Britain's railway to benefit passengers and support economic growth. [Electronic resource]: https://www.networkrail.co.uk/our-railway-upgrade-plan/digital-railway/. Last accessed 11.02.2018.

17. Zamyshlyaev, A. M. Information management in the transport sphere [*Informatsionnoe upravlenie v transportnoi sfere*]. *Nauka i tehnologii zheleznyh dorog*, 2017, Iss. 4, pp. 11–24.

18. Lyovin, B. A. Complex monitoring of transport infrastructure [*Kompleksniy monitoring transportnoi infrastruktury*]. *Nauka i tehnologii zheleznyh dorog*, 2017, Iss. 1, pp. 14–21.

19. Rozenberg, E. I., Rozenberg I. N., Tsvetkov, V. Ya., Shevtsov, B. V. Device for monitoring a mobile object. Patent for utility model. No. RU*95851* U1. *Registered 10.07.2010* [*Ustroistvo kontrolya podvizhnogo ob'ekta. Patent na poleznuyu model'. No. RU95851 U1. Zaregistrirovano* 10.07.2010].

20. Tsvetkov, V. Ya. Information interaction. *European researcher. Series A*. 2013, Iss. 11–1 (62), pp. 2573–2577.

21. Tsetkov, V. Ya. Integrated control of high speed railway. *World of Transport and Transportation*, Vol. 11, 2013, Iss. 5, pp. 6–9.

22. Danilov, K. V., Kapustin, N. I. Big Data Technologies in the Railway Infrastructure Sector [*Big Data v zheleznodorozhnoi otrasli infrastruktury*]. *Nauka i tehnologii zheleznyh dorog*, 2017, Iss. 4, pp. 25–33.

23. Lievin, B. A., Bugaev, A. S., Ivashov, S. I., Razevig, V. V. Distantly piloted aircrafts and the track security. *World of Transport and Transportation*, Vol. 11, 2013, Iss. 2, pp. 152–157.

24. D'Andrea, R. Can drones deliver? *IEEE Transactions on Automation Science and Engineering*, 2014, Vol. 11, No. 3, pp. 647–648.

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