Quantum computing in controlling railroads

Anatoly Khomonenko¹* and Maad M. Khalil²

¹Emperor Alexander I St. Petersburg State Transport University, 9 Moskovsky pr., 190031 Saint Petersburg, Russia
²University of Diyala, Department of Computer Science, Diyala, Iraq

Abstract. The paper discusses the main possibilities of using quantum computing and technologies in railway management, highlighting the most promising options and proposals for their application. One of the main objectives of the RZD "Russian Railways" is the research and implementation of quantum telecommunications as the basis for building promising network services. By focusing on improving solutions in the field of automation of railway transport process management, and taking into account the over-growing and changing needs of customers, RZD also wants to transform to digitalization and use quantum computing to create flexible management models, optimization of the structure and decision-making processes and the use of quantum computers both in information systems and in technical control systems. The study first identifies areas where the development of information technologies in railway transport is a must. Then the strategies and programs to digitalize these fields are discussed, how they are implemented is shown and finally a comparison is then made with other experiences from different agencies around the world. The Study concludes that the creation of quantum information systems with a contactless neuro-computer interface will solve several problems like the performance of duties by railway personnel, monitoring of significant objects of critical information and technical infrastructure, and public services. It is advisable to use quantum technologies and calculations in railway transport in the following main directions: the creation of a quantum telecommunication network; the introduction of quantum computing in the improvement of Blockchain technologies; use of quantum technologies to solve complex optimization problems. Keywords: Quantum Computing, Blockchain, Russian Railways, Railway Management, Automation Control, Digitalization.

1 Introduction

Digital transformation, in essence, represents the transformation of business processes into nonsense. The distinctive feature of digital transformation is the creation of new capabilities, processes, and services, not only increasing the efficiency and improvement of existing ones. The services created in digital transformation must meet three criteria: better, faster, and cheaper.

* Corresponding author: khomon@mail.ru
There are many terms within the concept of digital transformation, the central ones being Digitization and Digitalization. The term Digitization refers to the translation of information from physical media to digital media. For example, translating the contents of a book into electronic form, scanning a document, digitizing a painting, and recording a teacher's video course. Digitalization represents the initial creation of a new product in digital form. For example, recording a video course with animation or an interactive help system.

Many signals (telephone, fax, television) are analog. Their conversion into digital form provides several advantages: improved noise immunity of communication; microminiaturization of equipment based on the use of microcircuits, etc.; achievement of unification of organizational and technical methods and functional units based on the use of a unified element base.

Digitalization enables technological breakthroughs in business and competitive advantages. That is why it is considered one of the basic features of the Industry 4.0 phenomenon.

1.1 Quantum Computing

The increase in the power of digital electronic computers is approaching the limit of technological capabilities since the further development of modern technologies for the manufacture of large integrated circuits comes up against the need to use regions of space comparable in size to the interatomic distances in a crystal to store a bit of information. Shortly the technological limit of miniaturization in manufacturing technologies for large integrated circuits will be reached.

In search of a way out of this situation, research companies are showing increasing interest in projects related to the development of new types of hybrid computing devices. One of the most promising projects of this kind is the project to create a quantum computer.

In the field of quantitative computing, we note the work [2], which gives a picture of the significant features and capabilities of modern quantum computing technologies; [3], which characterizes quantum technologies in Russia; as well as the article [4], which describes modern modifications of Grover's quantum algorithm and their possible applications.

States and measurements in quantum systems. Any computational problem solved on modern digital computers can be represented as a problem of calculating a Boolean function because digital processors operate with binary representations of data. An elementary memory cell (trigger) at each moment can be in only one of two stable states and contains one bit of information.

The outcomes obtained in this area indicate that many computational problems can be solved on quantum computers much faster than on a conventional digital computer. The most notable outcome is the quantum algorithm for factoring integers into prime factors, which was proposed by P. Shor in 1994, and which allows factoring the number N into prime factors in O \((\log^3 N)\) time, i.e., e. is polynomial in the bit length of the input [1].

At present, there are single versions of quantum computers capable of solving a limited range of computational problems. In the theory of quantum algorithms, significant outcomes have been obtained over the past decades, and the field of quantum computing today is one of the most intensively developed areas of theoretical computer science.

1.2 Intelligent systems

Systems are currently occupying an increasingly important place in decision support systems and directions of digitalization. Among them is Artificial Neuron Network, which are computing systems based on the principle of biological neural networks - networks of nerve cells in a living organism - play a crucial role. Such systems "learn" to perform tasks by
looking at examples from a pattern. For example, in image recognition, they can learn to identify images containing individual elements (signs, faces, symbols, etc.) by examining examples and amusing the outcomes to identify elements in other images.

ANNs are used in a variety of tasks, including computer vision, speech recognition, machine translation, social network filtering, and medical diagnostics.

2 Methodology

The basis of the methodology of the article is the identification of the main priority areas for the development of information technologies in railway transport, the most significant achievements in quantum computing technologies, as well as the most important areas of their use for railway management.

The articles [5, 6] considered digital technologies in JSC "Russian Railways" used to increase flexibility, efficiency and quality of service provision. The vectors of innovative development, the main goals are shown in Table 1.

<table>
<thead>
<tr>
<th>Vectors</th>
<th>Basic goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital transfer-motion</td>
<td>Improving the efficiency and customer focus of the holding's business</td>
</tr>
<tr>
<td>Development of high-speed and high-speed highways</td>
<td>Accelerating economic growth and improving the quality of life of the population</td>
</tr>
<tr>
<td>The innovation ecosystem and the science and technology complex</td>
<td>Capacity building and cooperation in science, technology, and innovation</td>
</tr>
</tbody>
</table>

Let us also note the articles [7-9], which address the strategy of innovative development of the Russian Railways holding in terms of digital transformation and improvement of information technology of railroad management. Article [10] provides a brief description of the most advanced quantum computing ecosystems.

2.2 Programs for the digitalization of modern industries and economies

The Strategy for the Development of the Information Society in Russia for 2017-2030 defines the digital economy as an activity "in which the key factors of production are data presented in digital form, and their processing and use in large volumes, including their education, allows for significant improvements in efficiency, quality, and productivity in various types of products in the storage, sale, delivery, and consumption of goods and services compared to traditional forms of economy. The strategy formulates the concept of "information society" as follows: "This is an industrial society, a new historical phase in the development of civilization, in which the main productions are information and its highest form - knowledge" [11].

The term "digital economy" was one of the first to be used (Don Tapscott, [12]), which foresaw the role and importance of the Internet in the future economy. The article [13] the connection of the digital railway the digital economy is reveals.

The main goal of the direction concerning the formation of research competencies and technological advances is to create a system of support for exploratory and applied research in the digital economy, to achieve technological independence and competitiveness in all areas of digital technology, as well as to ensure national security.

The main goals of the information infrastructure direction are:
• Development of communication networks that meet the needs of the economy to collect and transmit data of the state, business, and citizens, taking into account the technical requirements of digital technology;
• Development of a system of Russian data centers that provide the government, businesses and citizens with accessible, sustainable, secure, and cost-effective data storage and processing services;
• Introduction of digital data platforms to meet the needs of government, business, and citizens;
• Creation of an effective system for collecting, processing, storing, and providing consumers
  • With spatial data that meets the needs of the state, business, and citizens for relevant and reliable information on spatial objects.

The goal of the direction concerning information security is to achieve a state of protection of individuals, society, and the state from internal and external information threats, which ensures the realization of constitutional rights and freedoms of man and citizen, decent quality and standard of living of citizens, sovereignty and sustainable social and economic development of the country.

The "Digital Railway" program includes areas for the development of Russian Railways' digital technologies in all areas within the framework of the "Digital Economy of the Russian Federation" program from big data and the industrial Internet to distributed registry systems, and virtual and augmented reality technology.

Among the areas of technical and technological development of the digital railway, within the framework of the program, a fundamentally important role is given to the introduction of modern telecommunication technologies and the modernization of the telecommunications infra-structure, which will make it possible to ensure the required quality of telecommunication services for the management of transportation and the development of corporate information, as well as to minimize the risks associated with the state of networks connections.

An important role is assigned to the organization and support of broadband (high-speed) access of corporate users to Internet resources, which means operating at a data transfer rate exceeding the maximum possible with dial-up access using a modem and a public telephone network. It is carried out using wired, fiber-optic, and wireless communication lines of various types.

2.3 Digital services

By (GOST R ISO 9000-2008. Quality Management Systems. Basic provisions and vocabulary) the concept of Service is defined as the outcome of at least one action, necessarily carried out in the interaction between the supplier and the consumer, and is usually intangible.

The provision of services in electronic form is carried out using information and telecommunication technologies, including the use of a single service portal, a universal electronic card, or a digital signature, including the provision of electronic interaction between organizations and applicants.

The term "digital services" means the electronic delivery of information, including data and content, on various platforms and devices such as the Web or mobile.

A digital service is a fully automated service that is controlled by the customer of the service, for example as an "application" on a mobile phone or tablet PC.

In addition, the digital service is typically an online service or contains a significant online component. For example, a digital service may use information from a separate computer system or another digital service that is accessed in real time over the Internet or an alternative
network. Two or more digital services can be combined to create one more powerful digital service for a customer.

Therefore, digital services can be divided into two classes:

- Services provided to the public to reduce the time of access to the service.
- Services provided to information systems and organizations to optimize asset value and equipment performance.

The term is more widely used in government circles in terms of providing a more convenient and efficient interaction between citizens and the public sector. However, it is no less important in the private sector in terms of improving the quality of customer service while increasing productivity.

The data provides transparency and enables optimal decision-making. By combining big data from equipment with information from other sources, such as weather forecasts and onsite maintenance reports, and performing deep analysis, experts can predict and prevent failures and identify opportunities to improve productivity, save energy and reduce costs. Digital services, at facilities, are harnessing the potential of data to increase equipment uptime and maintenance intervals, as well as improve overall productivity.

The transition to a digital business model leads to the transfer of all services both inside and outside the enterprise to a digital format. High competition leads to the need to develop the provided digital services, leading to their consolidation on a single platform and the provision of a single window on a single service portal.

### 2.4 The digital platform of Russian Railways

According to the IT strategy of the industry, the Digital Platform of Russian Railways has been developed. It has a structure that includes the following three blocks.

1. Corporate Governance:
2. Digital customer services.
3. Digital railroad.

The digital platform of Russian Railways consists of several key blocks, including digital client services for passengers and freight carriers, the Digital Railway block, which includes the management of production, the transportation process, and railway infrastructure facilities.

In addition, three basic areas permeate the entire structure of the digital platform: electronic document management, a single reference data and IT infrastructure, telecommunications, communications and information, and security.

### 2.5 Digital transformation in railway transport

In essence, digital transformation is a combination of operational and information technologies. This means that if earlier information technologies were used mainly for the exchange of information between participants in joint activities, now they will also be used in technological processes for the development and adoption of managerial decisions. That is, digital transformation involves a massive transition from automated information systems to automated control systems.

### 2.6 Prerequisites for digital transformation in railway transport

The consistent evolution of technology in the world creates new production opportunities for the "explosive" growth in labor productivity, called the "industrial revolution".
The "Fourth Industrial Revolution," also known as Industry 4.0, is characterized by the massive incorporation of cyber-physical systems into production and the servicing of human needs. The changes encompass many different aspects of life: the labor market, the living environment, political systems, the technological order, human identity, and others.

### 2.7 Key technologies of the integrated program "Digital Railway"

For this subsection, we note the articles [14-17], which address certain important issues. Based on analytical research by IDC, IBM, GARTNER, and Russian Railways experts, the Digital Railway Program includes the following digital technologies:

- Big Data;
- industrial internet of things (IoT);
- mobile applications, wireless technology;
- intelligent systems;
- high-speed data network;
- distributed ledger technology (blockchain).

Big Data is a technology, tool, and method for the rapid processing of structured and unstructured data in huge volumes to identify hidden relationships and the formation of outcomes.

Forecasting plays a key role in new approaches to railway transport management. Thus, the digitalization of management systems will make it possible to make decisions in a situation of much greater awareness of ongoing and future economic processes.

On the railway, automated information systems today provide huge amounts of data on the operation of infrastructure devices and rolling stock. With the development of these systems, the volume of data will continue to grow. Information processing will require the use of Big Data technologies.

The totality of systems represents a digital traffic control system for railway transport. It allows you to remove the operator from the control loop, and increase the level of automation, though, put, and optimal traffic control.

Internet of Things is a technology for collecting and transmitting information about the state of objects without human involvement for its subsequent automatic processing and the formation of control actions. The Internet of Things is a network of networks of uniquely identifiable objects capable of interacting with each other over an IP connection.

Mobile applications—software for customers and employees of Russian Railways, designed and adapted to work on mobile devices.

Intelligent systems—allow solving tasks that are considered creative, self-learning, and using and accumulating knowledge about the subject area. Intelligent systems (IS) of transport are designed to implement several global technologies for the transportation of goods and passengers.

High-speed data networks—a set of modern networks and telecommunications solutions that transfer large amounts of data at high speeds and with high reliability.

**Application areas of high-speed data networks for customers:**
- seamless Wi-Fi in trains and stations;
- Wi-Fi access to mobile services.

**Areas of application for high-speed data transmission networks for rolling stock:**
- remote control of locomotives;
- satellite navigation and positioning.

**Scopes of high-speed data transmission networks for infrastructure:**
- ensuring uninterrupted remote diagnostics;
- availability of computing architecture.
Distributed registry systems (blockchain). Blockchain represents a database in the form of a continuous chain of blocks and is stored simultaneously on many computers. New blocks in the chain are constantly being created. Each block again contains a group of records (transactions) and a header. After the block is formed, it is checked by other network participants and connected to the end of the chain. After that, no changes can be made to the block.

The main advantages of blockchain technology are:
- The ability to instantly create and verify transactions, thanks to which it is possible to optimize business processes, save money, and reduce the risk of fraud;
- Ensuring control and full transparency for system participants;
- Implementation of information dissemination in a distributed environment without a single operator, a third trusted party, and external regulation;
- Launching the execution of smart contracts in terms of moving objects (activating the "Internet of things");
- Guarantees an ultra-high degree of base security, and system resistance to hacker attacks.

Figure 1 shows a role model for the possible construction of a blockchain in Russian Railways. The network is formed by users interested in using this or that type of information.

![Diagram of blockchain roles](image)

**Fig. 1.** Role model of interaction.

Participants are divided into three types: light clients (simple users); validators, miners (block builders); auditors (checking the correctness of the data).


Auditor. Keeps a fully restored registry. Does not participate in consensus evaluation. Completely reduce the correctness of the data.

Light client. Does not store a copy of the registry. Makes entries to the registry and uploads data by contacting validators. Can check the proof that this entry is actually in the registry.

Possible areas for blockchain application in Russian Railways:
- cargo transportation, logistics (supply chain control by all participants);
- infrastructure services (monitoring the life cycle of rolling stock);
For the implementation of various projects, a single platform is needed that provides reliable and trusted data storage.

The blockchain platform of the distributed data registry is:

- a trusted environment for storing and exchanging correct data (one of the functions of Russian The railway is an auditor) among all participants in business processes;
- uniform principles and approaches to the implementation of solutions based on blockchain technology;
- Unified principles of information interaction with automated systems of process participants.

3 Overseas experience

Nederlandse Spoorwegen (Netherlands). Solution: Operational optimization of passenger train schedules, taking into account many factors (passenger traffic, weather, repair work, external events, rolling stock capabilities, etc.) using simulation tools with the choice of optimal options.

BNSF Railway (USA). Solution: Comprehensive track diagnostics by mobile laboratory cars (external service) with “big data” analysis for generating guidance on traffic modes, failure prediction, risk assessment, and dynamic repair planning.

International Union of Railways (UIC, Europe). Solution: Development of a roadmap for digital railways in Europe, including issues on information security, service approaches to the organization and management of passenger and freight transportation services, as well as the creation of a single digital platform that can create an ecosystem of carriers interacting according to common standards.

Network Rail (UK). Solution: A "Digital Railway" strategy has been developed to make better use of the infrastructure. The strategy contains recommendations for the development of paperless technologies, solutions for increasing track capacity during peak traffic by looking for opportunities to allocate additional traffic lines and the combined use of locomotive signaling, and solutions for improving transport connectivity (interactions between different modes of transport), as well as the transition to broadband communication of the 4th generation LTE.

Deutsche Bahn (Germany). Infrastructure digitalization projects (DB Netz AG) are being carried out - digitalization of the traffic schedule, development of an integrated transportation management system, and management of the maintenance of infrastructure facilities.

4 Conclusion

In railway transport, quantum technologies and calculations should be applied in the following main areas: the creation of a quantum telecommunications network; the introduction of quantum computing in the improvement of Blockchain technologies; use of quantum technologies for solving complex optimization problems.

References


5. M. Vasilenkov, E. Kuznetsov, V. Bespalov, et al., In E3S Web of Conferences 244, 11046 (2021)


15. S.E. Yunakovskov, M. Kot, N. Pozhar, et al., EPJ Quantum Technology 8(1) (2021)
