International experience of adaptation and application of digital ecosystems by industrial enterprises and clusters

Alexander Babkin[1*], *Larissa* Tashenova [1,2], *Dinara* Mamrayeva[2], *Barno* Kulzhambekova[2], and *Ilmidin* Yormatov [3]

[1] Peter the Great St.Petersburg Polytechnic University (SPbPU), St.Petersburg, Russia
[2] Karaganda Buketov University, Karaganda, Kazakhstan
[3] Ferghana Polytechnic Institute, Uzbekistan

Abstract. This article is dedicated to exploring the theoretical aspects of forming and managing digital ecosystems in industrial enterprises; the main advantages of implementing digital ecosystems in organizational activities and their distinctive features compared to customized digital ecosystems are also examined. The integrated use of digital technologies, digital platforms, and ecosystems enables efficient resource management, enhances labor productivity, and improves key performance indicators. Drawing on thematic and scholarly research, the article analyzes key strategic plans for the formation of digital ecosystems to enhance competitiveness and foster innovation in the industrial sector of leading foreign countries such as the United States, Germany, Japan, and China. The relevance and keen interest of these countries in studying the aspects of forming and implementing digital ecosystems in industrial enterprises for government and scientific organizations funding such research are noted. The article presents business cases on digitization and the development of digital ecosystems in the machine-building industry, using examples from American company "Tesla", French railway company "Alstom", and the nuclear industry, exemplified by the Russian State Atomic Energy Corporation "Rosatom".

1 Introduction

The rapid advancement of digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), and blockchain has revolutionized industrial operations worldwide. In response to these transformative forces, industrial enterprises have begun transitioning to digital ecosystems as a strategic approach to enhancing operational efficiency, stimulating innovation, and creating value across the value chain.

The development of digital ecosystems, based on digital platforms, has significantly altered the nature of economic activities at micro and sectoral levels, shaping a platform economy. The platform economy constitutes an economic system where digital platforms/unified digital platforms play a central role, serving as a "meeting place" for

* Corresponding author: pavel-mixailov1999@yandex.ru

various participants such as manufacturing companies, consumers, IT product developers, facilitating their effective interaction, exchange of goods and services, as well as information [1]. The digital transformation of industry leads to more flexible, scalable, and innovative business models, new forms of production using universal ICT, and the formation of strategic innovation-driven industrial clusters operating on a unified digital platform [2, 3].

Successful companies actively leverage digital platforms to gain advantage from network effects, thereby providing greater value to an extended user audience. A well-chosen digital strategy can help platform companies transcend the constraints imposed by geopolitical boundaries and foster international collaboration [4]. Digital platforms refer to information systems combining various elements (markets, companies, communities, and technological systems), aimed at creating value by facilitating direct interaction (communication, information retrieval, purchases, service provision, protection of intellectual property rights, etc.) and conducting transactions among multiple groups of external users (manufacturers, suppliers, developers, consumers).

Acting as key elements of the technological infrastructure of digital ecosystems, digital platforms mediate economic activities between economic agents and foster collaboration among business entities, the non-profit sector, and government bodies [5]. Digital platforms in industrial production have become the foundation for creating industrial digital ecosystems and changing the mode of production of goods.

The study of the formation and development of ecosystems in various industrial sectors over the past 5-7 years has become particularly pertinent. The structure, characteristics, and prerequisites for the formation of digital ecosystems in industrial enterprises, various ecosystem strategies, and the roles of companies within the ecosystem are among the contemporary trends in scientific research.

James Moore first introduced the concept of an ecosystem in economics and management in his work [6], describing a business ecosystem as an “economic community of interconnected organizations and individuals producing goods and services of value to consumers, also included as part of the ecosystem itself”. Michael J. Jacobides [7] defines digital ecosystems as “interacting organizations with modular architectures, not governed by hierarchical structures, and connected to digital networks”.

Digital ecosystems encompass a dynamic network of interconnected participants, including manufacturers, suppliers, distributors, and customers, facilitated by digital platforms and technologies. Unlike traditional business models, digital ecosystems emphasize cooperation, data exchange, and collaborative innovation among ecosystem participants [8].

For instance, Subramaniam M. in publication [9] identifies production digital ecosystems involving the production and sale of products, provision of services to customers, as well as consumption ecosystems evolving with the consumption of sold goods and provided services. Suuronena S. along with co-authors in the work [10] elucidate the prerequisites, challenges, and advantages of implementing and adapting digital business ecosystems.

Authors Bakhtadze N. and Suleykin A. in their article [11] introduced the concept of identification analysis with the aim of optimizing the management of industrial digital ecosystems, that involves the use of models (including predictive ones) of various fragments of digital ecosystems for real-time management. Cozzolino A. [12] investigated manufacturers’ adaptation systems to the emergence of new platform-based ecosystems and identified a process characterized by three consecutive phases: (1) selective collaboration, (2) cooperative competition, and (3) elective cooperation.

Thus, it can be concluded that in the current stage of economic development, a digital ecosystem represents a digital space where users are provided with services on the platform, allowing them to choose and pay for various products/services within a seamless process.

The aim of this scientific article is to explore the experience of advanced countries,

 https://doi.org/10.1051/bioconf/202414504048

industrial enterprises, and clusters in the adaptation and utilization of digital ecosystems.

The main objectives of the research are as follows:

– examination of theoretical aspects of digital platforms and industrial digital ecosystems;

– analysis of strategic plans for the digital transformation of economies of developed countries;

– study of business cases in the engineering, electrical, and nuclear energy sectors regarding the implementation, adaptation, and extensive use of digital ecosystems.

2 Methods

This study employed general scientific research methods, including – the method of analysis and synthesis, which were used to study approaches to the concept of "digital ecosystem"; the method of generalization – in analyzing ecosystem strategies of foreign countries; the case-study method – in examining practical examples of implementing and adapting digital ecosystems by industrial companies; in addition to these, specialized methods were also employed, including content analysis of scientific publications and graphical interpretation method.

3 Results

According to the ranking, compiled by the International Monetary Fund in 2023, the TOP-10 countries with the largest economies by GDP level included countries such as the USA, China, Germany, Japan, India, Brazil, and Canada (Figure 1).

Fig. 1. Top-10 World's largest economies, source: https://www.imf.org

In the United States, the transformation in the realm of building a digital ecosystem began with extensive activities of major companies such as Facebook, Amazon, Apple, Microsoft, and Google (Alphabet). China is the home to globally renowned technological giants including Alibaba, Tencent, Baidu, and Huawei, operating in various sectors including e-commerce, social media, search engines, cloud computing, and telecommunications, shaping the digital economy and driving technological innovations.

Germany is a pioneer in shaping the concept of "Industry 4.0" is a term characterized by the integration of digital technologies into manufacturing and industrial processes, and boasts numerous research institutions and technological hubs focused on advancing Industry 4.0 technologies and conducting research in areas such as cyber-physical systems, Internet of Things (IoT), artificial intelligence (AI), and advanced robotics to develop cutting-edge solutions for industrial enterprises.

Japan follows the Strategy for accelerated development – the "Society 5.0" Concept, focusing on the development of robotics and artificial intelligence technologies, and possesses unique technologies, innovative potential, and significant financial resources for organizing technology testing in the economy.

Based upon the experience of countries with the largest and most developed economies, such as the USA, Germany, China, and Japan, we will examine strategic programs for digital transformation of economies and the development of Industry 4.0., explore successful ecosystem strategies, innovative business models developed during the formation and management of digital ecosystems of industrial enterprises, as well as joint initiatives that have allowed states and organizations to harness the full potential of digital ecosystems and ensure sustainable growth and competitiveness (Table 1).

Table 1. Analysis of the development strategies of digital ecosystems in the USA, Germany, China, and Japan

Country	Strategies for digital transformation of the economy
USA	The process of digital transformation of the real sector of the USA and the formation of a smart industry at the macro level began in 2011 with the establishment of the Advanced Manufacturing Partnership (AMP) - a state-level intersectoral initiative coordinating the activities of the state, business, and academic communities in the field of innovative development of the industrial complex. Within the framework of AMP, recommendations were developed and implemented in the field of production technologies in three directions: • stimulation of research and implementation of developments; • educational programs and skills upgrading for personnel; • business environment (tax reform, technical regulation, trade, and energy policies). To stimulate the revival of the industrial potential of the USA in 2014 was adopted the "Act of revitalizing of American manufacturing and innovation", and in 2018 – the "Strategy for American leadership in advanced manufacturing". As a result of AMP activities in the period 2017-2022, the National network for manufacturing innovations was established – a union of research and production centers for the development of advanced manufacturing technologies. The institutions comprising the National network for manufacturing innovations support the commercialization of high-tech innovation projects and allocate over $500 million in annual budget funds for the implementation of about 700 projects. The technological center network created within the framework of AMP activities also helps implement other key initiatives to revive and support american industry: • COVID-19 Manufacturing Recovery – a program for the rapid recovery of the most affected industries in the pandemic; • Future Manufacturing Supply Chains – a program to create a digital ecosystem uniting domestic suppliers in the USA; • Clean Energy Manufacturing – a program for the development of clean energy technologies. In May 2023, the National strategic plan for Artificial Intelligence research and development was updated in the USA by the National Science

	and Technology Council's Committee on Artificial Intelligence. This plan follows national strategic plans for AI Research and Development released in 2016 and 2019 and contains nine strategies emphasizing a coordinated approach to international cooperation in AI research: 1) Making long-term investments in foundational AI research to promote innovative development and ensure US leadership in AI. 2) Developing effective methods for human-AI collaboration to productively complement and extend human capabilities. 3) Understanding and addressing the ethical, legal, and social aspects of AI, as well as ensuring that AI systems reflect the nation's values and promote fairness. 4) Ensuring the security and reliability of AI systems to verify the functionality and accuracy of AI systems and provide protection against cyber-attacks and data vulnerabilities. 5) Developing common sets of publicly available data and environments for AI training and testing, enhancing the potential for more innovative and fair results. 6) Measuring and evaluating the AI system through technical standards and benchmarking. 7) Better understanding the needs of the workforce in the sphere of the research and development of national AI, with the aim of strategically shaping a workforce ready for AI in America. 8) Expanding public-private partnerships to accelerate progress in AI. 9) Establishing a coordinated approach to international cooperation in AI research to address global challenges such as environmental sustainability, health, and manufacturing.
China	To accelerate the growth of China's digital economy, the "Made in China 2025" program has been adopted, spearheaded by the Ministry of Industry and Information Technology of the People's Republic of China, in collaboration with over 20 ministries and 50 esteemed scholars. This strategic initiative is aimed at fortifying China's manufacturing capabilities and delineates nine key objectives: 1) enhancing manufacturing innovation; 2) integrating information technologies with industry; 3) strengthening the manufacturing base; 4) promoting Chinese brands; 5) ensuring environmentally sustainable production; 6) advancing achievements in ten key sectors (new information technologies, numerical control systems, robotics, aerospace equipment, ocean engineering equipment, high-tech ships, railway equipment, energy-saving and new energy vehicles, energy equipment, new materials, biological medicine, medical devices, and agricultural machinery; 7) facilitating the restructuring of the manufacturing sector; 8) supporting service-oriented manufacturing sectors and production-related service sectors; 9) internationalizing manufacturing. China perceives intellectual manufacturing as a forefront area. To further its development, China will establish intellectual factories and digitized workshops as pilot projects in key domains; will accelerate the adoption of advanced manufacturing technologies and equipment, encompassing human-machine interaction, industrial robots, intelligent logistics management, and additive manufacturing in production processes. Digital transformation generates novel business models such as networked production, large-scale personalized customization, and remote intellectual services (R&D). China is witnessing emerging entrepreneurial innovations in the digital transformation of industries. For instance, WeChat Tencent has revolutionized communication, Alibaba's e-commerce has

	transformed the sales model, DiDi's internet taxi booking has altered transportation patterns, and drones have redefined the development model of aircraft industries. For example, Weichai Power has established a global collaborative R&D platform for engines, reducing their development cycle from 24 to 18 months. Sany Heavy Industries offers real-time monitoring and operation services for over 200,000 devices worldwide through an intelligent service platform. Space Cloud Network, through its industrial software delivery platform serving over 440,000 registered corporate users, achieved a turnover of approximately 19.3 billion yuan (Exchange rate of Russian Federation Central Bank: 1 Chinese Yuan – 12.8 roubles on 10.04.2024) (approximately 1.5 billion rubles).
Germany	In 2011, Germany introduced the concept of "Industry 4.0.". The primary document governing digital development in Germany is the "Digital Strategy 2025". The "Industry 4.0" platform serves as the core of Germany's digital ecosystem and is one of the largest networked communities, uniting policymakers, business and professional associations, trade unions, various companies, universities, and experts in the fields of science, technology, and business. Efforts within this platform have led to: • the creation of a reference architectural model for Industry 4.0 (RAMI 4.0), facilitating the systematic development of technological standards in this sphere; • the establishment and active implementation of an administrative framework within the industrial complex of Germany, serving as a unified virtual representation and communication interface, enabling conditions for intelligent networked interaction among machines, products, and people in production. The annually projected volume of private investments in the development of Industry 4.0. amounts to 40 billion Euros. Specialized tools within the Platform have been designed for informational and educational purposes to popularize the capabilities of Industry 4.0 for enhancing business efficiency, including: • an online map of the Platform, featuring information on 350 use cases of digital solutions in Germany, as well as the locations and functionalities of test benches and demonstration centers; • the Industry 4.0 Compass, providing an overview of smart industry development support services available within the territory of Germany; • the Industry 4.0 Laboratory Network and the Standardization Council for Industry 4.0. The companies such as Robert Bosch GmbH, Siemens AG, BMW AG, and TRUMPF GmbH & Co. KG have emerged as recognized leaders in promoting the "Industry 4.0" concept in Germany (https://www.unido.org/publications/working-papers).
Japan	In 2016, Japan developed a conceptual document outlining the digital transformation of its economy, including the sphere of material production, as well as the formation of institutional and technological foundations for modern society in the digital age. Through joint efforts of the government and the federation of large businesses in Japan, known as "Keidanren", the concept of "Society 5.0" was formulated, which describes the use of robotics and Big Data technologies in conjunction with the Internet of Things (IoT) and AI to transform human activities, improve their working and living conditions. To effectively achieve the goals of the "Society 5.0" concept in Japan, on the basis of the agency, regulating technology development, was established the Japan Institute for Promotion of Digital Economy and Community (JIPDEC). Important stages in the implementation of the "Society 5.0" concept into Japan's state policy practice included:

	• implementation of the New Robot Strategy adopted in 2015, which aimed to double the use of robotics in manufacturing and increase the use of robots in the service sector, thereby mitigating labor shortages; • implementation of the "Digital Transformation" program adopted in 2018, which aimed to study and analyze the problems hindering digitization in the business environment, find ways to overcome them, and implement more efficient business models and management systems. Within the framework of the project to create "smart cities", modeling of new processes "in miniature" is being carried out with the aim of creating a comprehensive solution that includes the synthesis of cyber and physical spaces, launching mechanisms of a new form of public self-government. A comprehensive innovation strategy, adopted in 2019, is being implemented, within which development and financing schemes for "smart city" projects have been defined, involving the participation of 11 government organizations, 356 major companies, universities, and research institutes, as well as 113 local government organizations. The key elements of Japan's smart industry development support ecosystem include the interactive Internet platform e-F@ctory (created by Mitsubishi Electric Corporation and the EdgeCross consortium), which forms the basis for "smart" manufacturing based on seamless integration of IT and production systems. The establishment of a national digital ecosystem, involving diversified players collaborating on mutually beneficial terms, is crucial for implementing the "Society 5.0" concept.
Note – complied by the authors.	

Let us also consider successful business cases of forming and developing digital ecosystems in manufacturing companies in the automotive and railway engineering, electric power, and nuclear power industries.

"Tesla" company (USA) stands out as a leader in the automotive industry; topping the rankings of companies transitioning to electric mobility and solutions in sustainable energy. A central factor contributing to Tesla's success is its robust digital ecosystem, which integrates cutting-edge technologies and services to enhance user experience, optimize productivity, and drive innovation [13, 14].

In 2023, Tesla produced 1.846 million electric vehicles and delivered over 1.8 million cars worldwide. The company's quarterly revenue amounted to $25.17 billion compared to $24.32 billion in the fourth quarter of 2022. Tesla's net profit for the fourth quarter of 2023 increased to $7.93 billion, or $2.27 per share, compared to $3.69 billion, or $1.07 per share, the previous year.

In 2022, the company managed to avoid emissions into the atmosphere of approximately 13.4 Mmt CO2e, compared to 8.4 Mmt CO2e in 2021 (for example, 13.4 Mmt is equivalent to more than 33 billion miles driven), achieved a 30% reduction in greenhouse gas emissions per vehicle, a 15% reduction in water usage at production facilities per vehicle, and 90% recycling of production waste (paper, plastic, metal).

Tesla employs an innovative approach to digitalization and has built a digital ecosystem covering a wide range of technologies, services, and products that the company offers to its customers:

– *electric vehicles*, manufactured using advanced battery and autopilot technologies, making them among the most innovative on the market;

– *software,* continually updated via wireless connectivity on all Tesla electric vehicles, including new features, performance enhancements, and safety improvements;

– *charging infrastructure*: Tesla owns and operates the world's largest fast-charging network, comprising over 45,000 Supercharger charging stations, which operate reliably at 99.95% uptime and are 100% renewable due to a combination of local resources and renewable energy sources;

– *vehicle management platform*: Tesla provides mobile apps and web portals to vehicle owners, allowing them to monitor and control their vehicles, including preheating or cooling the cabin, starting and stopping charging, and monitoring the vehicle's status;

– *autopilot and autonomous driving technologies* enable vehicles to operate without driver intervention on certain road segments;

– *energy solutions:* in addition to electric vehicle production, Tesla also manufactures solar panels, solar roofs, Powerwall energy storage batteries, and "Megapack" batteries capable of storing over 3.9 MWh of energy, enough to power an average of 3,600 homes for one hour. "Megapack" batteries are connected to "Powerhub" – an advanced monitoring and management platform for large-scale municipal projects and microgrids;

– *customer-centric approach* to building the Tesla digital ecosystem, based on customer needs and preferences. By implementing intuitive user interfaces, wireless updates, personalized recommendations, and remote vehicle diagnostics, Tesla prioritizes user experience. By employing data analysis and artificial intelligence, the company anticipates customer needs, actively addresses issues, and offers individual solutions, enhancing customer value and loyalty;

– *service and support:* Tesla provides customers with a wide range of service and support services, including warranty and post-warranty maintenance, as well as technical support through its service centers and online platforms.

"Megapack" batteries can also integrate with "Autobidder" – Tesla's machine learning platform for automated energy trading (Figure 2).

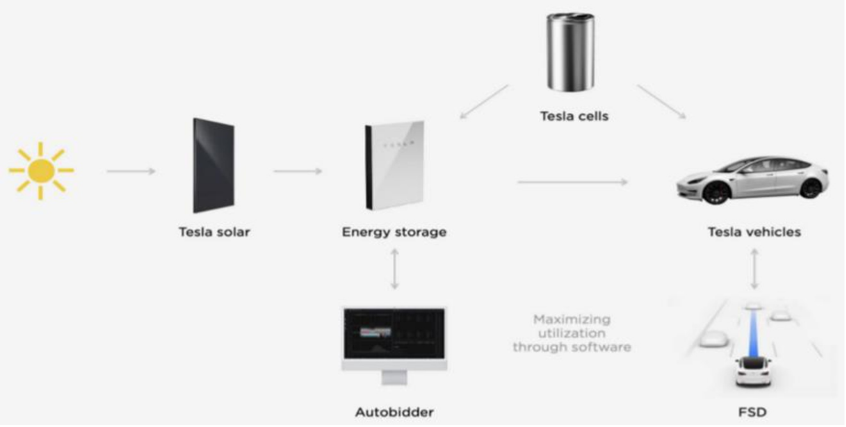

Fig. 2. Ecosystem of Tesla company, source: https://www.tesla.com/

Through the virtual platform for electricity trading "Autobidder", electricity producers, utility companies, and various organizations can independently profit from selling their available electricity reserves. The "Autobidder" platform aids in real-time asset management, optimizing their volume, adjusting strategies to achieve desired risk and profitability levels.

"Autobidder" has expanded its global battery portfolio to over 7 GWh of capacity, with real-time algorithms already returning over $330 million in trading profits to early investors in data storage systems. Since 2017, "Autobidder" has been successfully deployed at the Hornsdale Power Reserve in South Australia, increasing competition through market trading to lower energy prices.

"Tesla Full Self-Drive" (FSD) can complete a trip without any driver intervention. In 2021, Tesla launched the beta version of FSD 9.2 with an additional one-time payment of $10,000 and a monthly subscription package of $199.

Tesla's success is attributed to its unique business model aimed at disrupting traditional perceptions of automobiles by buyers, addressing vehicle safety concerns, increasing electric vehicle range, and providing superior customer service.

“Alstom” company (France) – is a global leader in the transportation sector in the era of digital technologies, producing high-speed trains of the TGV and AGV series, metros, monorails, trams, as well as “turn-key” systems, services, infrastructure, signaling systems, and digital mobility solutions. Alstom offers its diverse clientele a wide-ranging portfolio of industry solutions, due to its presence in 63 countries worldwide; the company focuses its activities on design, innovation, and project management where mobile solutions are most needed.

As of 2023, the revenue breakdown was as follows:

- rolling stock (locomotive and carriage manufacturing) - 53% of revenue;
- rolling stock repair and modernization services - 23% of revenue;
- track laying, electrification, signaling equipment, and station equipment- 9% of revenue;
- signaling equipment (railway traffic lights, control automation systems) -15%.

“Alstom” company is developing a digital ecosystem that includes:

- *digital solutions for customers* to enhance passenger experience during travel:

– leading Wi-Fi technology for a premium user experience;

– trip information systems (entertainment services, current news, weather, etc., delivered directly to passenger devices or via onboard displays);

– the use of Nomad passenger authentication processes allows train operators to recognize returning passengers;

– revenue generation: the ability to provide informational, entertainment, and commercial content creates future opportunities for high-profit margins.

- *fleet management solutions*, combining manufacturing expertise with diagnostic tools developed by the Nomad subsidiary and providing:

– fast and efficient access to real-time data and knowledge extraction;

– access to up-to-date information on the operation of key equipment and components onboard;

– access to historical diagnostic data for analysis at any time;

– know-how and tools for extracting and interpreting critically important operational data, enabling operators to perform real-time onboard analysis, automatically issue alerts (indications of impending equipment failures), and transmit relevant information to operational and maintenance depots.

Nomad combines its remote online condition monitoring tools (ROCM) with reliability-centered maintenance (RCM) methodology and railway transport knowledge to optimize equipment maintenance management and equipment availability.

These solutions enable quantitative improvements in economic efficiency, increase in reliability up to a 30%, increase in equipment availability up to a 20%, and energy savings through system-provided driver advice up to a 20%. It is also worth noting that:

- *Nomad network platform* is a reliable scalable network that allows onboard devices to interact with each other and the outside world, maintaining secure separation between passenger-oriented applications and systems responsible for safe train operation. This platform is distinguished by its flexibility, and provides potential for future system development, taking into account increasing passenger entertainment and information needs;
- *multimodal traffic orchestrator Mastria* helps city authorities achieve greater smoothness and throughput of various transport services by predicting and adapting to changes in passenger flows:

– optimizes all public transport resources;

– traffic planning and scheduling tool;

– responds to incidents across the city;

– engages all stakeholders in decision-making and implementation;

– provides advice on which procedures to perform and how to immediately implement corrective actions;

– predicts and adapts to changes in passenger flow;

– "mobility as a Service" provides high-quality information available through open-source platforms, where taxi services, bike rentals, parking, and other on-demand services can connect to a real-time information network and predict passenger flows.

As a proponent of sustainable mobility, Alstom aims to reduce its environmental footprint and promote environmentally friendly transportation solutions. Through its digital ecosystem, Alstom leads initiatives such as energy-efficient train operation, emission monitoring, and eco-driving optimization.

The Dynamic Maintenance Planning (DMP) system at Alstom is represented by HealthHubTM - a web-based solution with an innovative approach to condition-based and predictive maintenance of rolling stock, infrastructure, and signaling systems. An integrated set of decision support tools (sensors, cameras, lasers, data recorders, etc.) continuously monitor the condition of transportation infrastructure objects to prevent failures and revise standard maintenance practices.

DMP consists of 12 interacting applications capable of dynamically adapting during operation and at each stage of the maintenance plan, creating continuous interaction between operations and maintenance. The key advantages of DMP include automated flow of information, visibility and traceability of actions, avoidance of excessive maintenance, optimized operations, and increased efficiency in production activities (Figure 3).

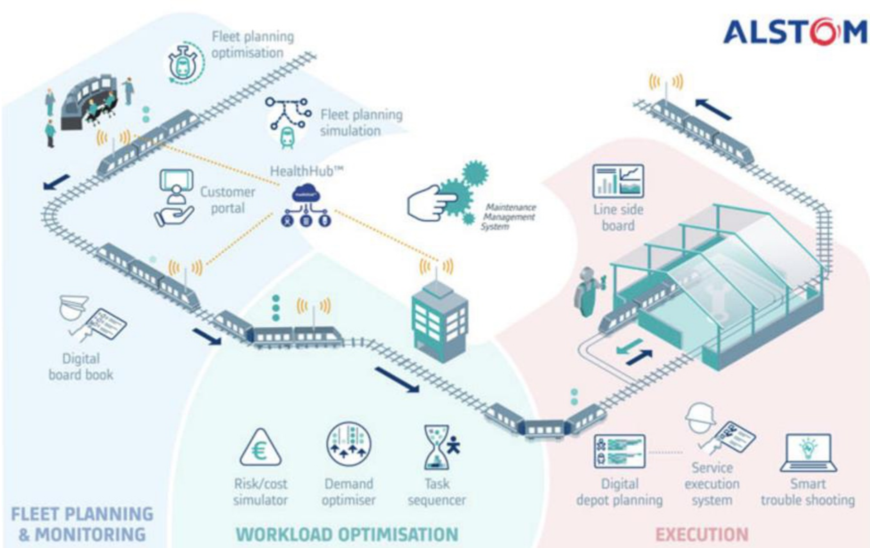

Fig. 3. Digital maintenance planning, Sourse: https://www.alstom.com

"Rosatom" (Russian Federation) – a state corporation, a diversified holding company that consolidates assets in energy, engineering, and construction. Its strategy focuses on developing low-carbon generation, including wind energy. The state corporation "Rosatom" is a national leader in electricity generation (accounting for approximately 20% of total production) and ranks first in the world in terms of the size of the order portfolio for the construction of nuclear power plants (with 33 energy units in various stages of implementation in 10 countries).

"Rosatom" is a digital company actively involved in internal digitization and the implementation of digital solutions in its operations, among which one of the significant technologies is the digital twin of nuclear power plants. The company also commercializes its activities in the field of digital products and acts as a supplier of these products to high-tech industries [15]. Currently, 30 countries around the world apply "Rosatom's" digital solutions. According to long-term plans, by 2030 "Rosatom" aims to achieve revenue of up to 4 trillion rubles (approximately 43.12 billion US dollars (Exchange rate of Russian Federation Central Bank: 1 US$ – 92.75 roubles on 10.04.2024)).

The "Rosatom" portfolio includes more than 60 digital products, services, and solutions, including: mathematical modeling systems (CAE-class), PLM systems, information technologies related to capital construction (TIM solutions), digital solutions for "smart" and safe cities, as well as digital infrastructure.

Key digital products in Rosatom's portfolio for enterprise and production management include the following:

– "*Atom Mind*" – an industrial digitization and predictive analytics platform (IoT);

– "*Sarus*" – product lifecycle management system (PLM);

– "*Digital Engineering*" – digital twins of industrial equipment; digital training simulators; digital enterprise modernization;

– *"Dedal-Scout"* – field service automation system;

– "*Almaz BI*" – industrial data analysis and visualization system (BI);

– "*Business Analytics*" – information dashboards for monitoring key indicators (BI);

– "*Atom.RITA*" – low-code business process automation platform (RPA);

– "*Atombot*" – ready-made solutions for automating routine operations (AI, RPA);

– "*Intellectum*" – digital platform for preserving critical knowledge and managing knowledge bases;

– "*Mathematical modeling and R&D: Logos*" - modular platform solution for engineering analysis and supercomputer modeling (CAE 2D/3D);

– "*Repeat*" - model-oriented design and mathematical modeling environment (CAE 1D);

– "*Volna*" - modeling, optimization, and monitoring system for gas transportation systems.

It is especially important to note the fruitful cooperation between the company "Rosatom" and the state, within which large digital projects are initiated in the country. For example, in 2020, the company began to create the "Unified digital platform of the nuclear industry", in which "Rosatom" serves as the technological core, consisting of subsystems for managing business processes, data, security, machine learning, and the analytical subsystem of Big Data. Additionally, the unified platform includes ecosystems of customers, suppliers, Russian government agencies, and international organizations (Figure 4).

Within the framework of the "Unified digital platform of the nuclear industry" program, the first services and modules were implemented in 2021, including the ""Digital Science" complex of digital services", enabling the collection of a digital footprint of scientific and technical developments and competencies, the preservation of all documents created during the preparation and acceptance of research, the recording of movement through levels of technological readiness, and the management of industry-acquired knowledge.

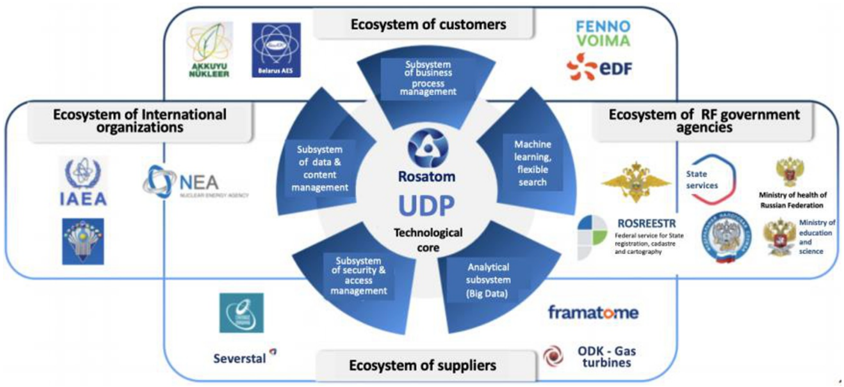

Fig. 4. Unified digital platform of the nuclear industry, source: https://www.rosatom.ru

A distinctive feature of Rosatom's activities is the implementation of a project for complete import substitution of foreign software on Russian important information infrastructure objects, which has allowed to increase the level of technological import independence of the nuclear industry and make a significant contribution to the development of the domestic IT market. Thus, from 2016 to 2023, "Rosatom" has developed 332 solutions included in the Unified Register of Russian computer programs and databases, which are reliable, accessible, and scalable. Consequently, the system of the American company OSIsoft has been replaced, and a priority for the company is the transition to domestic software for enterprise resource planning systems SAP ERP, SAP BI for consolidated reporting, SAP MDM for managing normative-reference information, and AVEVA Prism for predictive analytics. More than 95% of "Rosenergoatom" employees were transferred to the Russian operation system "Astra Linux" in 2023.

4 Discussion

It should be noted that today industrial enterprises find it important not only to implement digital ecosystems but also to transition to their customized versions, as this allows them to emphasize individuality and foster strategic alignment, providing competitive advantages in this fast-paced digital world.

Customized digital ecosystems are characterized by the ability to integrate specific solutions and technologies inherent to a particular industry; the ability to implement new functions, optimize processes, and adapt to changes in the business environment; ensuring a high level of data protection and access control, which is especially important for industrial enterprises and complex integrated industrial structures, for example, represented by industrial clusters; ensuring effective budget and resource allocation.

Examples of mass customization include companies that allow customers to independently design products (clothing, footwear) on their website. The consumer can choose the model, size, color, design, and other characteristics.

5 Conclusions

The following results were obtained during the conducted research:

– the concepts of digital platforms and digital ecosystems have been considered, and aspects of their implementation in the sphere of industrial production have been analyzed;

– the distinctive features and advantages of implementing a digital ecosystem, as well as the positive aspects of implementing customized digital ecosystems, have been identified;

– the relevance and great interest in studying the aspects of forming and implementing digital ecosystems of industrial enterprises in the context of digital transformation of their activities have been noted for governmental and scientific organizations financing such research in developed countries such as the USA, Germany, China, and Japan;

– an analysis of developed strategic plans for the digital transformation of the economy of the aforementioned countries has been conducted;

– practical examples of the implementation and development of digital ecosystems in the machine-building industry have been provided, using the examples of the American company Tesla, the French railway company Alstom, and the nuclear industry using the example of the Russian State Corporation for Atomic Energy "Rosatom".

Undoubtedly, successful formation of digital ecosystems requires a strategic approach, including ecosystem design, management mechanisms, and partnership strategies. Establishing mutually beneficial international cooperation with scientific organizations and industrial enterprises, applying innovative production and digital technologies of Industry 4.0, attracting public and private investments for digital transformation of the industry, developing domestic science, and increasing investment in R&D will contribute to increasing competitiveness and ensuring sustainable growth in the industrial sector of the Republic of Kazakhstan.

6 Acknowledgements

The study was carried out at the expense of a grant from the Russian Science Foundation No. 23-28-01316, https://rscf.en/project/23-28-01316/

References

1. Ignatova, T.; Platonova, E.; Pavlyukova, A.; Sroslak, G. Advances in Economics, Business and Management Research, **139**, pp. 359-362 (2020) https://doi.org/10.2991/aebmr.k.200509.063
2. Ayaganova, M.; Pritvorova, T.; Mamrayeva, D.; Tashenova, L. Social entrepreneurship: Business models and strategies for their development. Economic Annals-XXI, **178(7-8),** pp. 96-104 (2019). https://doi.org/10.21003/ea.V178-08
3. Babkin, A.; Tashenova, L.; Mamrayeva, D.; Andreeva, T.A. International Journal of Technology, **12(7),** pp. 1359–1368 (2021). https://doi.org/10.14716/ijtech.v12i7.5350
4. Cennamo, C. Academy of Management Perspectives, **35(2),** pp. 265–291 (2021). https://doi.org/10.5465/amp.2016.0048
5. Madanaguli, A.; Parida, V.; Sjödin, D.; Oghazi, P. Technological Forecasting and Social Change, **194(7),** 122606 (2023). https://doi.org/10.1016/j.techfore.2023.122606
6. Moore, J.F. Harvard Business Review, **71(3),** pp. 75–86 (1993). https://hbr.org/1993/05/predators-and-prey-a-new-ecology-of-competition
7. Jacobides, M.G.; Cennamo, C.; Gawer, A. Strategic Management Journal, **39(8),** pp. 2255–2276 (2018). https://doi.org/10.1002/smj.2904
8. Chae, B.K. A International Journal of Information Management, **45**, pp. 83-94 (2019). https:// doi.org/10.1016/j.ijinfomgt.2018.10.023
9. Subramaniam, M.; Iyer, B.; Venkatraman, V. Competing in digital ecosystems. Business Horizons**, 62 (1),** pp. 83–94 (2019). https://doi.org/10.1016/j.bushor.2018.08.013.

10. Suuronen, S.; Ukko, J.; Eskola, R.; Semken, R.S.; Rantanen, H. CIRP Journal of Manufacturing Science and Technology, **37**, pp. 414–426 (2022). https://doi.org/10.1016/j.cirpj.2022.02.016
11. Bakhtadze, N.; Suleykin, A. Annual Reviews in Control, **51**, pp. 56–64 (2021). https://doi.org/10.1016/j.arcontrol.2020.11.001
12. Cozzolino, A.; Corbo, L.; Aversa, P. Journal of Business Research, *126*, pp. 385–400 (2021). https://doi.org/10.1016/j.jbusres.2020.12.058
13. Liu, J.; Meng, Zh. Procedia Engineering, **174**, pp. 965 – 972 (2017). https://doi.org/10.1016/j.proeng.2017.01.248
14. Latini, A.; Campiotti, C.A.; Pietrantonio, E.; Viola, C.; Peral, V.; Fuentes-Pila, J.; Sagarna, J. Agriculture and Agricultural Science Procedia, **8** pp. 657 – 663 (2016). https://doi.org/10.1016/j.aaspro.2016.02.088
15. Timokhin, D.; Bugaenko, M.; Putilov, A. Procedia Computer Science, **169**, pp. 445–451 (2020). https://doi.org/10.1016/j.procs.2020.02.227